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A State of the Environment Report

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A State of the Environment Report

Canadian Perspectives on Air Pollution

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State of the Environment Reporting
Environment Canada

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Environment Canada

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Think Recycling!

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Preface

The environment is our only life-support system. As we approach the 21st century, however, there are indications that we are severing this lifeline.

Canada, like many other countries, has implemented State of the Environment (SOE) Reporting. Written for Canadians interested in their environment, SOE Reporting takes many forms: fact sheets, reports, newsletters, data base, and a five-year national report, to be published in 1991. SOE is a partnership that will increasingly involve federal, provincial, and territorial governments, private industry, academia, nongovernmental organizations, and the individual citizen.

Careful, objective analysis and interpretation of data will monitor conditions and significant trends in the health of our environment. Of equal importance are the explanations for these trends and the actions we are taking to sustain and enhance the natural environment. By increasing awareness of the state of our life-support system, we should be stimulated to protect it through better decision making and management.

Canadian Perspectives on Air Pollution is one indicator of the health of our country. If you are interested in obtaining more information on SOE Reporting, please write to:

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Summary

In the final decade of the 20th century, the global community continues to grapple with an unprecedented array of air quality and atmospheric pollution problems. Not only is local air quality deteriorating as the world's nations pollute the air, but there is also a growing body of evidence to suggest that the composition of the whole atmosphere is changing rapidly as pollutant levels build.

In this State of the Environment report, we discuss the causes of some of these local and atmospheric air pollution problems, as well as their general effects on both human health and the environment. We then detail the sources, emissions, levels, and environmental and human health effects of the six common air pollutants—airborne particulates, sulphur dioxide, carbon monoxide, nitrogen oxides, ground-level ozone, and hydrocarbons. Characteristics of toxic air pollutants are more difficult to describe because there are so many of them. Here, we illustrate the variety of approaches used in their study—by single chemical, as in the case of lead; by class of chemicals, as for polycyclic aromatic hydrocarbons; by polluting activity, for example, residential wood combustion; and by geographical area, for instance, Junction Triangle, a small, industrialized urban area with local sources of pollution.

There are several regional and global air pollution issues of importance to Canadians. Here, we examine the issues of acid rain, pollution in the Arctic, depletion of ozone in the stratosphere, the "greenhouse effect" or global warming, and atmospheric radioactivity. Finally, we discuss the significance of air pollution problems to the Canadian public and the efforts by government to prevent air pollution through legislation.

Homeowners reject $1 million payoff for factory's odours
Acidic fog threatens mountains in Quebec
Air we breathe is getting cleaner, says report
Air pollution up marginally
Citizens bring air pollution charges
Whitehorse bylaw is an effort to curb woodsmoke pollution
Air quality
Ill winds still blow

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Units of measure

Area

km^2	square kilometre(s)

Concentration

ppm	parts per million; 1 ppm is analogous to 1 second in 11.57 days
ppb	parts per billion; 1 ppb is analogous to 1 second in 31.69 years
ppt	parts per trillion; 1 ppt is analogous to 1 second in 31 688.1 years
g/L	grams per litre
$\mu g/m^3$	micrograms per cubic metre
ng/m^3	nanograms per cubic metre
pg/m^3	picograms per cubic metre

Distance/size/length

m	metre(s), approx. 3.3 feet
µm	micrometre (micron), 0.000 001 metre
km	kilometre, 1000 metres

Energy

GJ	gigajoule, or 1 000 000 000 joules, about the energy contained in 30 litres of gasoline
PJ	petajoule, or 1 000 000 000 000 000 joules, about the energy used for all purposes in Toronto or Montreal about every 17 hours
TWh	terawatt hour, or 1 000 000 000 kilowatt hours; a 100-watt light bulb burning for 10 hours uses 1 kWh of electrical energy

Volume

L	litre; 1 imperial gallon is about 4.5 litres
dL	decilitre, or 0.1 litre
mL	millilitre, or 0.001 litre
m^3	cubic metre

Weight

g	gram(s)
kg	kilogram, or 1000 grams
mg	milligram, or 0.001 gram
µg	microgram, or 0.000 001 gram
ng	nanogram, or 0.000 000 001 gram
pg	picogram, or 0.000 000 000 001 gram
t	tonne; 1 tonne = 1000 kg

Abbreviations

CFC	chlorofluorocarbon
DDT	dichlorodiphenyltrichloroethane
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
VOC	volatile organic compound

Chapter 1

The origins of air pollution

Introduction

In the final decade of the 20th century, the global community continues to grapple with an unprecedented array of air quality and atmospheric pollution problems. When the world's nations pollute the air within their own boundaries, they create local air quality problems, which are of immediate concern to us because they affect our health and welfare. Many nations unintentionally pollute their neighbours' air, as well. There is also a growing body of evidence to suggest that the composition of the whole atmosphere is changing rapidly as pollutant levels build, which will be of perhaps even greater importance than deteriorating local air quality because the composition of the atmosphere is a determinant of climate on Earth. Climate influences where people live, how they behave, and the activities they carry out. Fundamental aspects of our existence, such as the nature and distribution of plant and animal life, the length of growing seasons, the extent of snow cover, and the depth of lakes and rivers, are influenced by climate.

In this chapter, we describe changes in Earth's atmosphere and climate over time, then discuss those man-made processes that have led to air pollution problems in Canada.

The early atmosphere

Earth and its atmosphere have changed continually and, at times, dramatically over the 4.5 billion years since the planet formed. Consider how the atmosphere's oxygen content has varied, for example. Geological and biological evidence suggests that initially the atmosphere contained no oxygen. Single-celled bacteria and blue-green algae are thought to have been predominant early life forms about 3.5 billion years ago. Over time, oxygen released by these organisms during their respiration processes led to an oxygen-rich atmosphere. This transition is believed to have preceded the appearance about 500 million years ago of multicellular plants and animals (McMenamin 1987). Photosynthetic processes (in which plants transform carbon dioxide and water into carbohydrates and oxygen) developed at about the same time and accelerated the oxygen enrichment of the atmosphere and, thus, the diversification of life forms. The sun's ultraviolet radiation, which previously had reached Earth's surface undiminished, was absorbed significantly by the oxygen in the atmosphere, bringing ultraviolet radiation levels closer to those we experience today.

Dinosaurs were relative latecomers on the planet about 200 million years ago, and they thrived until their sudden and largely unexplained disappearance about 65 million years ago. Scientists suspect that the oxygen content of the atmosphere fluctuated during this period, but the atmosphere at the time of the dinosaur was already under the powerful influence of biogeochemical cycles. Through these cycles, soil, water, and living organisms absorb and emit gases, thus exerting a stabilizing effect on the atmosphere's composition and Earth's climate (Siever 1974). Earth was also much cooler then than in its formative years, but gases continued to escape from beneath its surface into the atmosphere, as they do today. Gravity, which prevents most atmospheric gases from escaping to outer space, produced an atmosphere that is densest close to Earth's surface, with "thin" air at high altitudes. Strong forces, both physical and biological, shaped the character of the air we breathe today.

The changes that Earth has undergone over the ages are generally not viewed as being catastrophic. The pace of change was slow, and the change took place over an unfathomable length of time. The planet's atmosphere, at least in human terms, has become more hospitable over those billions of years.

Climate change

Earth's climate is also known to have changed radically throughout history, with the first significant presence of ice occurring several million years ago (Ingersoll 1983). Since then, there have been recurring periods of glaciation, in particular in the northern hemisphere, the most recent of which peaked about 18 000 years ago. Glaciation is thought to be caused by periodic changes in the orientation of Earth as it orbits the sun, which reduce the amount of solar radiation received at high latitudes (Covey 1984), promoting ice formation. In the more distant past, according to fossil records, Earth was too warm to support such large-scale ice formation. The gradual warming at the end of the most recent ice age, which occurred over several thousand years, was once considered to be an abrupt climate change. But

even more abrupt climate change—i.e., significant change over several decades—is believed to have occurred in Europe and in Greenland as the ice age ended and as climate-modifying heat exchange between ocean currents and the atmosphere strengthened (Kerr 1988). Abrupt climate change has been associated with historical transitions in plant and animal life, such as the extinction of dinosaurs (Crowley and North 1988).

The dynamic nature of the atmosphere is evident from its history. There is no doubt that many factors, not just human activity, influence the environment. The forces acting to alter the condition of the atmosphere today are driven not only by natural biogeochemical processes but also by atmospheric pollution. How much our knowledge of past changes will aid us in preparing for future atmospheric change remains to be determined.

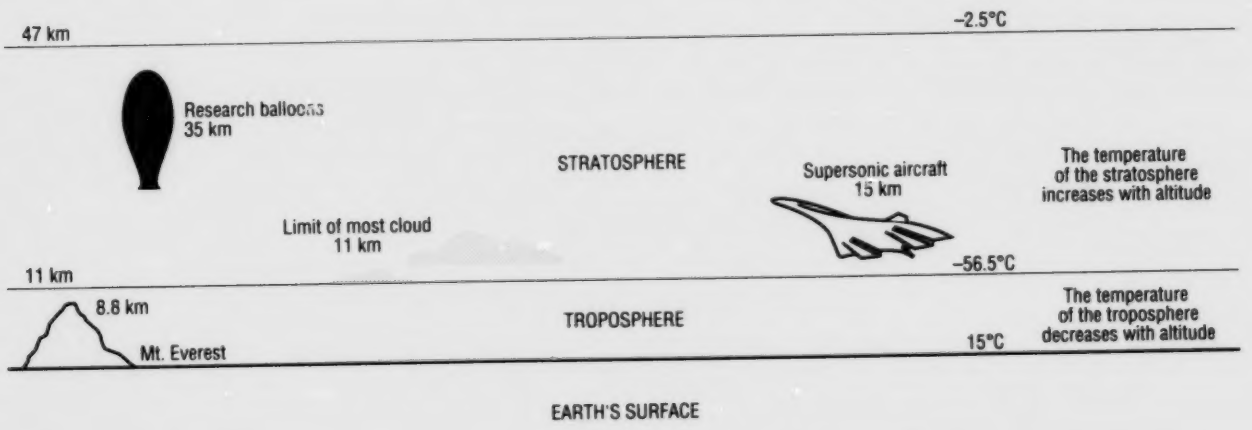
The atmosphere today

Earth's atmosphere today supports the lives and activities of an estimated five billion people, along with at least five million species of plants and animals (May 1988). Life is much more pleasant when the air we breathe is clean and the atmosphere is functioning as it should to protect and support life on Earth.

Scientists have determined that the atmosphere contains several layers, each of which has a distinct composition essential to its function. From an air pollution perspective, the two most important layers are the ones closest to Earth—the troposphere and the stratosphere (Figure 1). The air of the troposphere must be of good quality for animal life to breathe and for plant life to thrive, but good air quality is being compromised throughout the world by the presence of air pollutants. Moreover, the levels of tropospheric gases such as carbon dioxide, which control the rate of heat loss from Earth and thus moderate climate, are increasing through pollution. This will result in a warmer average climate on Earth.

The stratosphere, the layer of the atmosphere extending from about 11 km to about 47 km above Earth, contains gases that absorb much of the sun's harsh ultraviolet radiation before it enters the troposphere. Recent scientific evidence suggests that one of these gases, ozone, is being depleted in the stratosphere as a result of air pollution, and that the amount of harmful radiation reaching Earth is increasing as a result (see Chapter 5). Not long ago, the suggestion that the human race had the capacity to alter the global atmosphere in ways as significant as this through normal human activity would have been met with some skepticism. Unfortunately, we know today that, despite its vast-

Figure 1
The vertical structure of the lower atmosphere and the change in temperature with altitude



SOURCE: Based on Atmospheric Environment Service, Meteorological Operational Course, September 1989, Toronto.

NOTE: The height of the troposphere varies with latitude.

Types of substances that pollute

Pollutants occur in the atmosphere in all three physical states: solid, liquid, and gas. Although there is no universally accepted nomenclature for air pollutants, several terms are commonly used. The term *gases* signifies pollutants that exist only in the gaseous state within the normal temperature range of outdoor ambient air (approximately –40 to +40°C). Four of the six common air pollutants—sulphur dioxide, nitrogen dioxide, carbon monoxide, and ozone—are examples of gases. The atmosphere may also contain a variety of organic gases. Propane, the gas used to heat barbecues, is an example.

Vapours are the gaseous form of substances that are usually thought of as being solids or liquids at ambient temperatures. Polluted air usually contains a variety of vapours. Gasoline, solvents, and mothballs are examples of substances that pollute because they vaporize. Natural biological processes also release vapours to the air. The vapours may remain free in the air or they may condense on particles floating in the air, depending on the temperature.

Aerosols consist of fine solid particles and droplets of liquid, both about the size of the droplets released from the spray cans of some familiar household products, such as hair sprays and oven cleaners. Aerosols are small enough to stay suspended in the air for some time. Gases such as sulphur dioxide and nitrogen dioxide contribute to the aerosol when they react chemically in the atmosphere to produce sulphates and nitrates in the form of fine particles.

Particulate matter is a term used to describe the material that can be filtered from the air; in practice, this includes both aerosols and larger particles, such as dust, soot, ash, fibre, and pollen, with particles ranging in diameter from 0.005 to 100 μm. Particulate matter is not a clearly defined chemical or physical entity. The technique used to filter the air—in particular the pore size of the filter used—must be specified if particulate matter samples are to be compared. The terms particulate matter, *suspended particulate*, *total suspended particulate (TSP)*, and *airborne particles* are used interchangeably in the air pollution field. From an air pollution control perspective, it is the particulate matter of nonbiological origin, rather than that of biological origin (e.g., pollen), that is important.

Within the broad category of toxic air pollutants, there are various classes of compounds, such as PAHs, polychlorinated biphenyls (PCBs), dioxins, furans, and pesticides. At ambient temperatures, some individual compounds in these classes can exist only in the vapour state; others exist both in the vapour state and bonded to airborne particles; and others are only found bonded to airborne particles at ambient temperatures. In the air pollution field, these classes of compounds are termed *semivolatile organic compounds*.

Volatile organic compounds is the term used to describe collectively the organic gases and vapours that are present in the air, excluding methane. *Hydrocarbons* is a broader term for organic gases and vapours and includes methane.

ness, the farthest reaches of the atmosphere have become contaminated and altered through pollution.

Dry, unpolluted air in the troposphere would have a composition close to that shown in Table 1 (Stern *et al.* 1984). However, the air we breathe is never completely dry or unpolluted. Air always contains water vapour; particles of dust, pollen, soil, fibrous minerals, and ash; and other gases, such as sulphur dioxide, nitrogen dioxide, ozone, and carbon monoxide, all of natural origin. At the best of times we breathe air that isn't "pure." In polluted air, sulphur dioxide, nitrogen dioxide, ozone, carbon monoxide, particulate matter, and organic gases and vapours are found at levels higher than those found naturally in the purest air; these substances are referred to as the "*common air pollutants*." Although there is only a small number of common air pollutants, there are thousands of other substances that potentially can pollute the air. These substances, which include such compounds as lead and polycyclic aromatic hydrocarbons (PAHs), are referred to as "*toxic air*

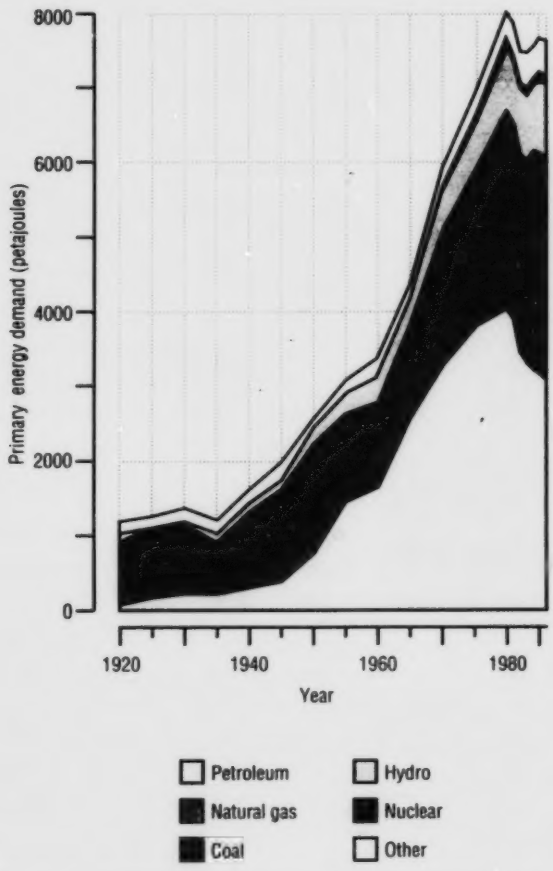
Table 1
The approximate composition of dry, unpolluted air in the troposphere

Component	Concentration (ppm)[a]
Nitrogen	780 900
Oxygen	209 400
Argon	9 300
Carbon dioxide	315
Neon	18
Helium	5.2
Methane	1.0–1.2
Krypton	1.0
Nitrous oxide	0.5
Hydrogen	0.5
Xenon	0.08
Organic vapours	~0.02

SOURCE: Stern *et al.* 1984.

[a] ppm = parts per million (i.e., the proportion by volume of each component gas in one million volumes of air). 1 ppm is analogous to 1 second in 11.57 days.

Figure 2
Primary energy demand in Canada, 1920–1986



SOURCE: Data provided by Jean Fortin, Energy, Mines and Resources Canada.

NOTE: 1 petajoule = 10^{15} joules, approximately 165 000 barrels of oil. Primary energy demand is the total requirement for all uses of energy in Canada and includes the energy used by the final consumer, intermediate uses of energy in transforming one energy form to another, and energy used by suppliers in providing energy to the market.

pollutants" because they are perceived as being dangerous to breathe even in very small amounts and because many of them are not found naturally in pure air. They are mainly the products, by-products, and wastes of our technological age.

There are additional air pollutants that do not belong in the common and toxic air pollutant categories. For example, gases such as carbon dioxide and methane, which control the rate of heat loss from Earth, are called "greenhouse gases," and chlorofluorocarbons and halons, gases that deplete the stratospheric ozone layer, are referred to as "ozone-destroying substances" (see Chapter 5).

Causes of air pollution

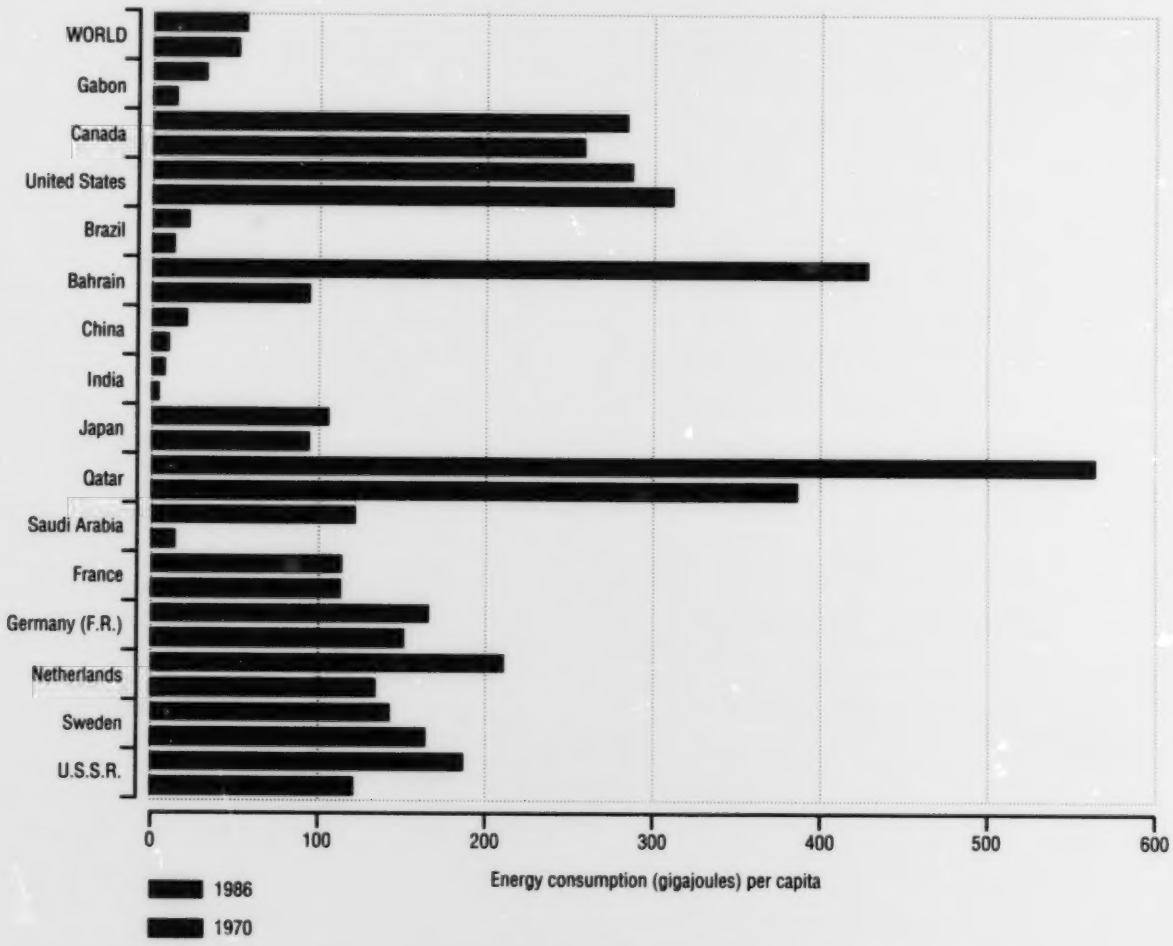
Which of man's activities contribute air pollutants to the atmosphere? A significant contribution comes from activities directly related to the production and consumption of energy. Energy is essential to all aspects of life. Large amounts of energy are used to heat and cool homes and buildings, to provide food and water, to power vehicles and equipment, and to drive industrial and manufacturing processes. Future survival and development require the continuing availability of energy (World Commission on Environment and Development 1987). However, the requirement for energy must be met in more environmentally sound ways than in the past, as the development and use of energy have had serious implications for the health and safety of people and the quality of the environment worldwide (Energy Options Advisory Committee 1988).

The cost of energy and the general health of the economy play important roles in determining how much energy we use and how we derive that energy. The demand for energy is affected by its price, especially when prices fluctuate widely. Energy prices also affect economic growth in all sectors. Even when energy prices are fairly stable, economic growth slows when energy demand declines, and vice versa (National Energy Board 1988).

About 1980, the decline in demand for high-priced oil, in combination with a worldwide slowing of economic growth, led to shifts in the sources of energy used (Figure 2). Increased use of other fuels, such as natural gas, as well as energy conservation measures and improved pollution control, have contributed to the general downward trend in some of the common air pollutants associated with energy consumption. However, the increased use of such fuels as coal and wood may worsen certain air pollution problems or lead to new ones. For example, much of the world's coal is of high sulphur content, and burning coal produces sulphur dioxide, a pollutant implicated in several of Canada's serious air pollution problems. The increased popularity of wood burning leads to increased exposure to woodsmoke, which contains particulate matter with toxic air pollutants bonded to it. Any increase in fossil fuel combustion will increase emissions of carbon dioxide, a greenhouse gas implicated in global warming and climate change.

The future demand for energy will therefore have important implications for air quality. Canadians are among the highest per capita energy consumers in the world (Figure 3), partly because of the climate and the size of the country (hence long distances travelled), and partly because of inefficient energy use (Energy Options Advisory Committee 1988). Demand for energy peaked in 1980 and, in response to rising oil prices, declined by about 8.5% between 1980

Figure 3
Change in energy consumption per capita, 1970 and 1986



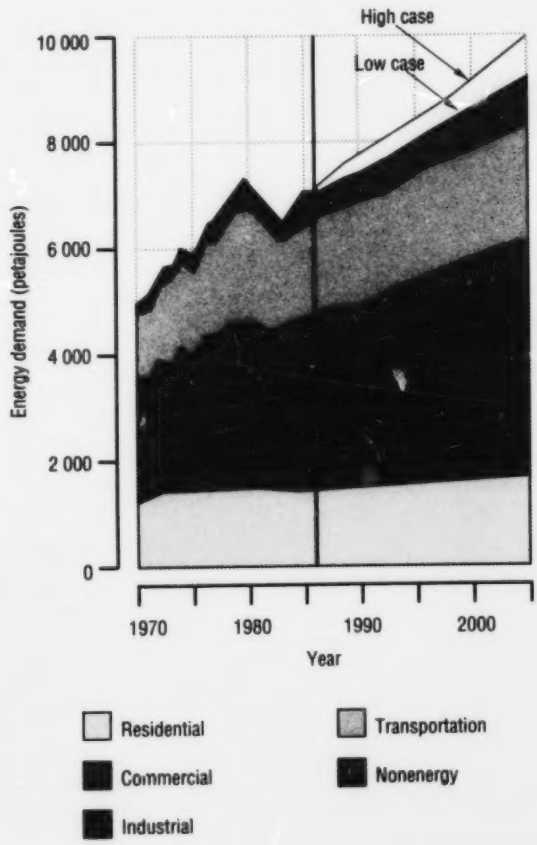
SOURCE: World Resources Institute/International Institute for Environment and Development 1988.

NOTE: 1 gigajoule = 10^9 joules. Consumption represents commercial energy sources only. Data for fuelwood and biomass consumption, the primary source of household energy in many developing countries, are not included.

and 1983, a period of recession worldwide. Demand then increased by about 7.7% between 1983 and 1986 during the economic upturn, mainly because of increased industrial and transportation requirements. Energy demand is predicted to continue to rise at least to the year 2005 (Figure 4). The extent of the rise will depend on future oil prices and economic growth.

Over the past 10 to 15 years, however, consumers adopted energy-saving practices, anticipating higher future energy prices. Homes became better insulated, energy-efficient vehicles and appliances were introduced, government programs encouraged conservation, unnecessary lighting was curtailed, and incentives coaxed consumers to use more efficient energy sources, such as electricity and natural gas. More energy will be used in the future even though the efficiency with which we use it is predicted to increase by 0.7–1.0% annually between 1986 and 2005 (National Energy Board 1988), and this increased use must be factored into predictions of future air quality.

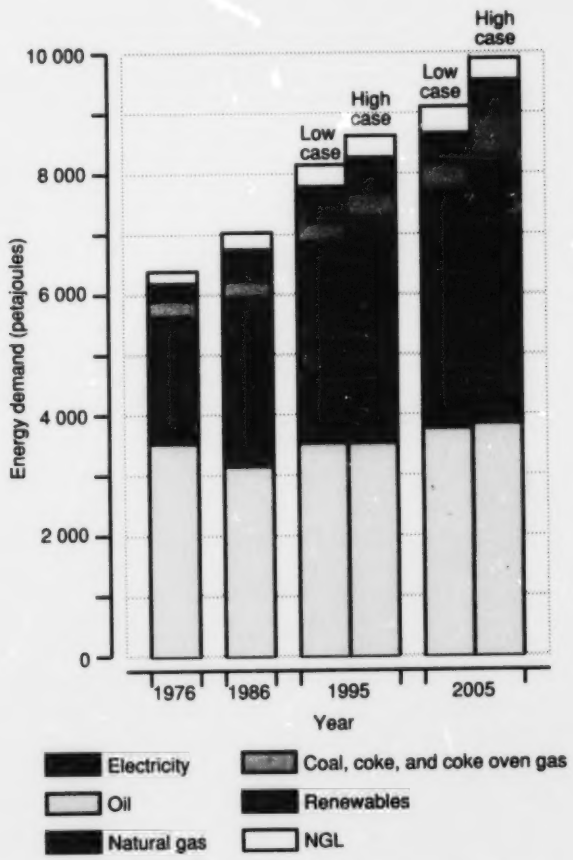
Figure 4
Total end-use energy demand in Canada,1970–2005



SOURCE: National Energy Board 1988.

NOTE: 1 petajoule = 10^{15} joules, approximately 165 000 barrels of oil. End-use energy demand includes energy used by final consumers for residential, commercial, industrial, and transportation purposes, and hydrocarbons used for such nonenergy purposes as petrochemical feedstock. Low case is based on the assumption of low economic growth and low world oil prices. High case is based on the assumption of high economic growth and high world oil prices. Demand for 1970 to 1986 is actual demand. Demand from 1987 to 2005 is projected demand.

Figure 5
End-use energy demand by fuel type in Canada, 1976–2005



SOURCE: National Energy Board 1988.

NOTE: 1 petajoule = 10^{15} joules. NGL = natural gas liquids, defined as the hydrocarbons ethane, propane, butanes, and pentanes, or a combination thereof. Renewables = hog fuel (wood waste, bark, sawdust), pulping liquor (burnable by-products of chemical wood pulping), wood, solar, municipal solid waste, and steam. Low case and high case are explained in Figure 4. End-use demand is defined in Figure 4.

Predicted changes in sources of energy also have important implications for air pollution (Figure 5). By the year 2005, 21% of Canada's energy demand will be supplied by electricity. Electricity production is predicted to rise by between 36 and 51%, i.e., from 457 terawatt hours in 1986 to somewhere in the range of 620–687 terawatt hours in 2005. The important consideration, from an air pollution perspective, is the way in which that electricity will be produced. For example, the amount of electricity produced from coal is predicted to approximately double between 1986 and 2005 but will still be less than 20% of the energy produced. Nuclear-generated electricity is expected to grow between 50 and 68% over the same period. Both are potential sources of radioactivity in the air.

There are other causes of air pollution that are not directly related to the production and consumption of energy. Industrial production of chemicals and minerals, the manufacture and use of consumer products, agricultural and forestry practices, waste treatment and disposal—all these can lead to air pollution problems because they are sources

Table 2
Pesticide sales in Canada, 1986

Category[a]	Amount of active ingredient (t)
Herbicides	24 687
Insecticides	2 857
Fungicides	3 385
Fumigants	1 403
Miscellaneous[b]	636
Total pesticides	32 968

SOURCE: Based on the results of a joint Agriculture Canada – Environment Canada pesticide registrant survey (Environment Canada 1987).

[a] Material and wood preservatives, nonagricultural disinfectants, and the bacterial pesticide *Bacillus thuringiensis* were not included in the survey.
[b] Miscellaneous category includes rodenticides, animal repellents, growth regulants, agricultural spray oils, etc.

Table 3
Daily per capita generation of municipal solid waste, 1985

Location	Amount (kg)
United States	2.0
Canada	1.7
Norway	1.3
Switzerland	1.0
United Kingdom	1.0
Sweden	0.9
Germany	0.9
Japan	0.9

Source: US Environmental Protection Agency 1988.

of both toxic and common air pollutants. The demand for these products and services is a reflection of lifestyles and consumer attitudes.

Prediction of future chemical production and emissions of toxic air pollutants from the chemical industry in Canada is difficult. The chemical industry, by virtue of its close ties with the production of consumer goods, is subject to the vagaries of the economy. The production of chemicals in Canada fluctuates significantly from year to year, in part as a result of changes in the growth rate in consumer spending. Accidental releases of chemicals are impossible to predict. Releases through the use of chemicals—for example, in the manufacture of plastic products, by small enterprises such as dry cleaners, and by consumers, who apply paints and floor coatings in their homes—are difficult to quantify.

Changes in consumer spending and foreign competition also affect the mineral industry. The mineral industry, which includes mining and production of such metals as aluminum, copper, nickel, zinc, and iron, is a significant source of emissions of particulate matter and sulphur dioxide and, depending on the processes used, can also be a source of emissions of various toxic air pollutants.

The greatest air pollution concern associated with agricultural and forestry practices is the use of pesticides. Almost 33 000 t of active ingredients registered under the Pest Control Products Act were sold in Canada in 1986 (Table 2). Organochlorine pesticides such as DDT and chlordane are of particular concern. They have been widely used throughout the world and have been dispersed in the global environment in part through long-range atmospheric transport. Although the use of these pesticides has been cut back in recent years, their long-term stability in the environment has led to the establishment of a complex process of exchange between the atmosphere, land, and surface waters. Therefore, organochlorine pesticides are commonly found throughout the environment in mid-latitudes as well as in the sub-Arctic and Arctic, in whales, polar bears, and seals (Norstrom and Muir 1989). The finding of comparable flows of pesticides into the Arctic and into the more temperate environment in southern Canada, based on the analysis of snow, indicates the importance of atmospheric transport. Levels of pesticides are generally lower in the Arctic than at mid-latitudes. The contribution of atmospheric deposition to the total pesticide burden in the Arctic is unknown. The same processes that transport pesticides to the Arctic also transport industrial pollutants, which cause the phenomenon of Arctic haze (see Chapter 5).

Waste treatment and disposal practices can also pollute the air. About 750 million tonnes of solid waste were generated in Canada in 1980, of which approximately 1.7% (13 million tonnes) was municipal waste, 8.1% (61 million tonnes) was industrial waste, and 90.2% (676 million tonnes) was waste from energy production, agriculture, mining, demolition, dredging, and sewage treatment (OECD 1985). By 1985, the amount of municipal solid waste generated had risen to an estimated 16 million tonnes, an increase of 27% (OECD 1989). Canadians are among the highest per capita generators of municipal solid waste (Table 3).

Incineration of waste can lead to air pollution. However, in the case of municipal solid waste in Canada, only about 8% (over one million tonnes) is incinerated, 2% is recycled, and 90% goes into landfills. An unknown quantity of air pollutants is emitted from landfill sites as the solid waste slowly decomposes. As of 1988, five large incinerators (municipal or industrial) and numerous smaller ones were in operation in Canada (Finklestein 1989). To reduce emissions, most of these incinerators use pollution control

devices, such as electrostatic precipitators (devices employing high voltages to charge aerosols and collect them by attraction on oppositely charged surfaces), baghouses (large filters), and lime scrubbers (devices that wet and neutralize the aerosols with lime solution and collect them by collision on solid surfaces). The pollutants of concern from incineration of municipal solid waste are dioxins and furans, metals, acid gases (such as hydrogen chloride), and carbon monoxide.

About six million tonnes of the waste generated in Canada (1986 estimate) was hazardous waste. One-quarter of this was organic material. Industry-owned and -operated incinerators, licensed by provincial authorities, dispose of some of the hazardous waste. There are three other incinerators—in Quebec, Ontario, and Alberta—where hazardous wastes can be incinerated. The type of hazardous waste that can be handled by each incinerator varies. The site in Alberta, for example, is the only one in Canada permitted to burn PCBs, the most familiar example of hazardous waste. Despite the high efficiency of destruction of hazardous wastes by incineration, the public generally resists the construction of incinerators. Improper transport and storage of hazardous wastes awaiting disposal can lead to accidental release to the air.

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Chapter 2

The effects of air pollution

Introduction

Why is air pollution significant? Without clean air, good health and a sound environment for the lasting use and enjoyment of future generations will remain elusive goals. Polluted air affects our world in many ways. Apart from the direct physical damage to health, the environment, and materials, the less tangible economic costs related to lost productivity, diminishing availability of natural resources, and social disruption must also be taken into account to determine the overall effect.

Human health effects

There is no doubt that air pollution in the middle part of this century posed a direct hazard to human health. In 1930, 64 people died as a result of a "killer fog" in Belgium's Meuse Valley; in 1948, a similar incident caused the deaths of 20 people in Donora, Pennsylvania. In December 1952, a four-day fog in London, England, caused about 4000 deaths. As a result of these and similar incidents, strict measures to control air pollution were put in place in North America and much of Europe. Although the air in Canada is now much cleaner than it was 20 or even 10 years ago, there is still some concern that contaminants in the air may be continuing to affect human health in less obvious ways.

There are wide ranges in both the severity and types of health effects that might be associated with air pollution. Acute effects occur immediately or within a few days of exposure, whereas chronic effects may not be noticed for months or years. Different pollutants cause different adverse health effects, and mixtures of pollutants may in fact cause greater effects than those caused by the individual compounds in the mixture. This section emphasizes the human health effects that result from the inhalation of pollutants. Air pollutants can also contaminate food and drinking water; however, there are other reports in preparation that deal with this subject in detail.

Acute or short-term effects

Asthma. — Asthma is a fairly common disease in which airflow is periodically obstructed when the air passages narrow or become plugged with excessive mucus. Symptoms of asthma include shortness of breath, coughing, and wheezing. There is tremendous variation in the severity of symptoms among asthmatics: many require extensive medication, whereas others can manage without any medication.

The causes of asthma are not clear; possible factors include stress, heredity, and exposure to such environmental agents as allergens or dusts. Although it is not known whether air pollution itself can cause asthma, air pollution can increase the chances of an asthmatic person having an attack (NRC 1985). Asthmatics appear to be particularly sensitive to sulphur dioxide (Brain *et al.* 1988).

Respiratory infection. — Specific air pollutants, such as sulphur dioxide, nitrogen dioxide, and ozone, have been associated with increases in incidence of such respiratory infections as colds, influenza, sore throat, pneumonia, and bronchitis. Studies in animals suggest that certain pollutants actually interfere with the clearance system in the respiratory passages, leaving the lungs less able to clear out invasive bacteria and viruses.

Changes in lung function. — Pollution can cause temporary changes in the capacity of the lungs to take in and force out air (NRC 1985). These changes are quite subtle, but significant decreases in lung function have been observed at air pollution levels that do occur in Canada from time to time. It is not yet known whether repeated transient decreases in lung function could result in long-term effects on respiratory health.

Chronic or long-term effects

Chronic obstructive pulmonary disease. — The term chronic obstructive pulmonary disease refers to several conditions, including chronic bronchitis, emphysema, and small-airway disease, all of which are indicative of irreversible damage to the respiratory system. The disease is really a chronic limitation of airflow, which leaves affected persons less able to fight off infections and which reduces their quality of life.

It is difficult to study the relationship between the incidence of chronic obstructive pulmonary disease and environmental conditions, for several reasons: people move from place to place, past exposures to air pollution may have been heavier, and the lag time between exposure and onset of a disease is not known. Factors known to contribute to chronic obstructive pulmonary disease are old age, heredity, cigarette smoking, occupational exposure to such materials as coal dust and certain chemicals, and exposure to high concentrations of sulphur dioxide and particulate matter (NRC 1985). Chronic bronchitis has been found to be more common in areas of higher sulphur dioxide and particulate matter pollution than in cleaner areas (Ferris *et al.* 1986).

Lung cancer. — Lung cancer has many origins and can result from interaction among a variety of agents. Tobacco smoking is clearly the most important agent, followed by some occupational exposures (NRC 1985). Polluted air can contain a variety of contaminants, some of which (such as benzo(a)pyrene) are known to cause cancer in experimental animals. High levels of ambient air pollution are also thought to enhance the activity of other carcinogenic agents, such as tobacco smoke (NRC 1985).

Sensitive populations

Severe pollution incidents in the past have shown that the elderly and those with existing respiratory disease are most susceptible to the ill effects of air pollution (Brain *et al.* 1988). Smokers may also be more sensitive to pollution. Strenuous exercise increases the amount of pollutants to which the respiratory system is exposed, and people are often warned to avoid exercising when pollution levels are high. Unborn children are also more susceptible to some pollutants than adults; thus, pregnant women are often considered to be a sensitive population. There is also concern that children repeatedly exposed to high levels of air pollution may suffer reduced lung development. The implications of this for their long-term respiratory health are not clear.

Epidemiological studies in Canada

The only way of assessing the real-life effects of air pollution is to perform epidemiological studies. This field of research is used to examine the relationship between health effects in the population and certain environmental conditions, such as air pollution. There are several limitations to epidemiology, however. For example, results are often difficult to interpret because of variations in people's lifestyles. A problem encountered when studying outdoor air pollution is that the quality of air breathed in by an individual can vary greatly depending on his day-to-day activities. Because most Canadians spend about 85% of their time indoors, the air that they are breathing is very much influenced by indoor activities such as smoking. A 1983 study in Hamilton identified parental smoking as having the strongest association with respiratory illness in children; air pollution appeared to play only a minor role (Pengelly *et al.* 1983). Also, chemicals in the air at the workplace can have a big influence on a person's total exposure to contaminants. These limitations notwithstanding, epidemiology is still the best way of ascertaining if current levels of air pollution are affecting the health of a population.

Two recent epidemiological studies by the Department of National Health and Welfare on the effects of transported acidic air pollutants compared the lung function of children living in relatively nonpolluted regions of Manitoba and Saskatchewan with that of children living in southwestern Ontario, a region with fairly high levels of acid air pollution (see Chapter 5). On average, the children in Ontario had a 2% lower lung function than the Prairie children. The children in Ontario also had higher frequencies of chest colds, inhalant allergies, stuffy noses, and coughs with phlegm. Similar studies in the United States support the finding that children in more polluted cities suffer more colds and upper respiratory infections than children in cities where the air is cleaner (Dockery *et al.* 1989).

Other studies indicate that air pollution may indeed be increasing the amount of illness in the population. One study examined the relationship between air pollution, temperature, and the number of people admitted to hospital for respiratory ailments. The investigation, conducted in southern Ontario during the summers of 1974 to 1984, found that greater numbers of people were hospitalized for respiratory problems on days when pollution levels, particularly sulphur dioxide levels, were elevated (Bates and Sizto 1989).

In a different type of study examining the short-term effects of transported air pollution, researchers from the Department of National Health and Welfare found that the lung functions of girls attending a summer camp decreased when high levels of air pollution, particularly acid and ozone, occurred at the camp (Raizenne *et al.* 1989). Other studies in Canada and the United States have also found that high levels of air pollution can cause reversible decreases in lung function (Ferris *et al.* 1986).

Social and economic consequences

Respiratory disease has social and economic consequences. Minor conditions such as colds and influenza can result in lowered productivity and time lost from work. More serious problems that require hospitalization are obvi-

ously costly for the medical system and ultimately for all of society. If air pollution does in fact increase sickness, then it is contributing to the social and monetary cost of caring for those afflicted, and it diminishes individual quality of life.

Environmental effects

Much less is known about the effects of air pollutants on the environment than about their effects on human health. This is because the protection of the environment from the adverse effects of air pollutants historically has been a secondary consideration in the drive for clean air, often as part of a broader goal of protecting the welfare of citizens. Often overlooked were the less obvious indirect effects on human health as a consequence of air pollutants having entered the environment and interacted with it in some way. As a result, many environmental objectives, guidelines, standards, and regulations were established that did not address the full spectrum of potential human health and environmental effects.

In recent years, however, the belief that air poilution causes serious widespread damage to the environment has prompted studies that are beginning to present a more balanced picture. For example, some plants have been shown to be as sensitive as, or even more sensitive than, humans to some air pollutants. Knowledge of the effects of air pollutants on animals other than humans is still very limited; however, evidence based on tissue and organ analysis suggests that some of the more persistent air pollutants eventually accumulate in plants and animals.

What is well understood now is that the air is the primary route of entry of many pollutants into the environment, and that, once there, these pollutants behave in rather complex ways. For some pollutants, for example, the pathway through the environment involves long-range transport through the air and the transfer of pollutants between air, water, and land. There is evidence that some pollutants, such as organochlorine compounds and certain metals, find their way into food and drinking water, and that other substances of a corrosive nature, such as acids, and highly reactive substances, such as ozone, chemically alter the natural environment and man-made materials. The result may be direct damage or, in some instances, the release of other toxic substances into the environment through what are essentially chain reactions.

Effects on plants

Effects of air pollution on natural vegetation and on agricultural crops can be studied experimentally by exposing the plants to known levels of air pollutants while they are growing either under controlled conditions in a greenhouse or partially or wholly enclosed in chambers in the field. Pollutants such as acids, ozone, sulphur dioxide, and nitrogen oxides have the potential to damage plants. The injury may occur through direct contact with gases, vapours, or particles (referred to in the air pollution field as "*dry deposition*" of pollutants) or through contact with precipitation that contains the pollutants (i.e., "*wet deposition*"). The pollutants may be deposited directly on the plant, be taken into the plant through its normal respiratory processes, or be taken up through the plant's root system.

Effects on plants may be subtle, with little or no visual evidence of damage, but there can also be obvious short- and long-term damage. Four categories of injury to plants have been identified: contamination with toxic components, loss of quality, yield loss, and decreased aesthetic value (Ontario Ministry of the Environment 1983). Obvious signs of injury to plants include colour change in foliage (in well-defined areas or full colour change), dead foliage or dead areas on the foliage, and leaf or needle drop. Less obvious changes, such as reduced rate of photosynthesis or changes in plant enzyme activity, may also be detected. Reductions in seed crop, radial growth, and total mass harvested may result from pollution.

Effects on forests

Significant changes in forest growth and vitality have been observed recently in Europe and North America. This change is referred to as forest "decline." Many factors, including air pollution, are thought to influence forest decline because they lead to tree weakening or tree death. Tree "dieback," or loss of foliage, is a commonly observed symptom of weak trees in a declining forest. Foliar yellowing and injury may also be evident. Dieback is not confined to forests: trees in urban settings may also exhibit symptoms of dieback. Forest decline is a recently recognized problem, distinct from the heavy damage to forests and trees that was caused earlier in the century by high levels of pollutants from clearly identifiable sources, such as sulphur dioxide from smelters. Long-range transport of increasing levels of acidic pollutants from many sources is a major concern in forest decline. This may have begun to influence forest growth 20 to 30 years ago.

The major factors implicated in forest decline are climate, infection, air pollutants, soil acidification, and nutrient deficiencies (Schulze 1989). The wide range of factors potentially involved in forest decline are not easily studied in the laboratory under controlled conditions, and many questions remain to be answered. To help understand how these factors act to influence decline in forests, three classes of influencing factors have been proposed (McLaughlin 1985):

(1) *Predisposing factors* that lead to tree weakening over the long term: climate, soil moisture, genetic makeup of the tree, soil nutrients, air pollutants, and competition from other trees and species.

(2) *Inciting factors* that trigger sudden physiological shocks in weakened trees: insect defoliation, frost, drought, salt, air pollutants, and mechanical injury.

(3) *Contributing factors* that accelerate forest decline: bark beetles, canker fungi, viruses, root decay fungi, and competition from other trees or species.

Air pollution is considered to be both a predisposing and an inciting factor and may exert effects at the cellular level (e.g., on enzyme activity), the physiological level (e.g., on photosynthesis), the tree growth level (e.g., on the amount of growth), and the forest productivity level (e.g., on reproduction).

In Canada, damage and decline symptoms are evident on red spruce in the Appalachians in Quebec. Foliar damage to white birch has been observed near the Bay of Fundy. Damage at lower levels and frequency is also reported on alder, mountain ash, mountain maple, largetooth aspen, and trembling aspen (Magasi 1989). Decline symptoms are evident on sugar maple in Quebec and Ontario. Forestry Canada operates the Acid Rain Early Warning System to detect and monitor changes in the appearance of forests. When damage is detected, research to determine the nature of the problem is initiated. This has been done for birch trees in New Brunswick and maple trees in Quebec (Hall 1989).

Effects on animal life

Animal life can be affected by air pollutants in many ways, often with serious consequences. Air pollutants that are inhaled, deposited on food and ingested, or absorbed through the skin may lead to direct injury or death. The earliest reports of such direct injury date back to the 1800s (US Department of the Interior 1980). For example, in Germany in 1887, fallow deer are reported to have been killed by arsenic from a silver foundry.

Today, many air pollutants are known to affect animal life directly. Fluorides deposited on forage have been found to cause injury to domestic and wild animals by altering dental and skeletal formation (National Academy of Sciences 1971). Pesticide ingestion by birds, through the food chain, has been shown to lead to egg shell thinning (Peakall and Kiff 1988), although this may not always be the result of air pollution. The effects of the acidification of lakes as a result of acid rain (see Chapter 5) on the size, abundance, and structure of fish populations are well documented (NRCC 1981).

In addition, air pollutants that acidify the environment, cause tree dieback and forest decline, alter the colour of the environment (with loss of the protective advantage that colour affords some animals), or influence climate can indirectly affect wildlife by changing their habitat or the availability of preferred prey, or both (Blancher and McAuley 1987).

Problems associated with contamination by metals emitted directly to the air or released from soil and rock through acidification have been found. For example, based on laboratory studies, aquatic invertebrates are likely to have been lost from some lakes where cadmium levels are high. Elevated levels of cadmium have been found in moose liver, and elevated levels of mercury have been found in fish muscle. The elevated levels of metals do not appear to affect these animals, but predators, especially those at the top of the food chain—for example, loons, herons, otters, and mink—may experience both acute and chronic effects following the ingestion of mercury and other contaminants. The effects of metals tend to be more severe in young, developing birds and mammals than in adults (Scheuhammer 1987). The health of man, the ultimate predator, can also be compromised following the ingestion of contaminated wildlife. These are only a few examples of the effects experienced by wildlife as a result of air pollution.

Effects on materials

Accelerated deterioration of both metals and nonmetals (e.g., paint, coatings, wood, paper, stone, marble, sandstone, cement, mortar, brick plaster, masonry, ceramics, glass, textiles, and plastics) can result from air pollution (NRCC 1986), although the effects of natural weathering are difficult to distinguish from pollution effects. The corrosive agents include sulphur dioxide, ozone, and airborne acids. Monuments, statues, paintings, gravestones, buildings, and other works of art have been damaged.

Effects on climate

Air pollutants have been linked to climate change, with implications for changes in rainfall, temperature, drought frequency, length of seasons, hailstorms, soil erosion, insect activity and viability, soil moisture, and vegetation growth. The most well-studied effect of air pollution on

climate is the phenomenon of global warming, but climate on the regional scale may also be affected. Deposition of air pollutants onto Arctic snow may darken the snow, which leads to greater absorption of solar radiation and a warmer Arctic climate. Both of these topics are discussed in Chapter 5.

Conclusion

The broad range of potential effects of air pollution on human health and the environment is a concern for everyone. Although air quality in Canada has dramatically improved in recent years, people's health may still be adversely affected in areas where pollutant levels are high. The implications of this are of special concern to children, to the elderly, and to people who already suffer from respiratory disease, as air pollution may aggravate and worsen existing conditions. As well, the suspected environmental effects of air pollution, such as the dying forests, the corroding buildings and statues, and the decreasing numbers of fish and other wildlife species, need to be dealt with. The complexity of air pollution problems presents one of the great challenges to future policy makers. How will the direct effects of air pollutants on human health, the effects on the environment, and the indirect effects on both (including the effects on climate) all be factored into decision making regarding environmental objectives and legislation?

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Chapter 3

The common air pollutants

Introduction

Two high-profile international issues are hallmarks of early air pollution problems in Canada (Katz 1962). In the 1930s, sulphur dioxide emissions from the large lead–zinc smelter in Trail, BC, were found to be causing significant damage to crops and forests in neighbouring Washington state. By the late 1940s, activities of the general public and expansion of industry and ship traffic to and from the Great Lakes had collectively led to unacceptable air pollution in the Detroit–Windsor area. These issues stood out because of the publicity generated by Canada–US efforts to resolve them, and they overshadowed a more widespread progressive deterioration of air quality. By the 1960s, however, the rapid increases in population growth and industrialization that followed the Second World War had caused an obvious worsening of air quality throughout the country (Katz 1963).

By the late 1960s, given the extent of air pollution and the recognition that air pollutants moved freely across political boundaries, there was a clear need to foster cooperation and coordination between the various levels of government in Canada. The Federal–Provincial Committee on Air Pollution—renamed the Federal–Provincial Advisory Committee on Air Quality in 1984—was established for this purpose in 1969, even before the formation of the federal Department of the Environment and the passage of the federal Clean Air Act* (see Chapter 6). The common air pollutants were the major cause of concern at that time, and federal and provincial air pollution control authorities agreed in 1969 to establish the National Air Pollution Surveillance (NAPS) network, indicative of a broader, emerging, cooperative federal and provincial effort to control air pollution.

The NAPS network has several functions:

- to determine the nature and extent of air pollution across Canada in order to facilitate the planning of control and abatement programs, both provincially and federally;
- to provide the basic data required to link pollution levels with health and environmental effects, such as through epidemiological studies;
- to provide a measurement of the effectiveness of air pollution control programs;
- to disseminate clear and concise information to the public on a regular basis on both air quality across the country and progress in the attainment of national air quality objectives;
- to provide the basis for quickly reacting to unusually high pollution levels within major urban areas; and
- to provide a factual basis for negotiations leading to air management programs in international and interprovincial transboundary air pollution problem areas.

Provincial agencies operate and maintain the air monitoring stations on a day-to-day basis. The federal government supplies the bulk of the instrumentation, assists in the provision of certain support services, such as sample analysis where required, and, in general, coordinates the operation of the network on a national scale. This division of responsibilities results in a near-even split in the overall cost of operating the network. In 1989, the network covered 52 cities and had a total of 380 monitors at 132 stations. The NAPS network has generated most of the information for this report on trends and levels of the common air pollutants in Canada. Provincial and municipal authorities also operate air pollution monitoring networks in many jurisdictions.

Provincial and federal governments also work cooperatively to supply the data needed to develop estimates of emissions of pollutants. There is, however, considerable uncertainty associated with the determination of emissions of the common air pollutants. A large number of diverse, widespread sources must be considered. For some sources, emissions have been measured directly, such as by sampling smokestacks; for others, only estimates are available. Emission levels calculated in the 1980s are generally more accurate than those calculated in the 1970s because the methodology used has improved and because more sources are now being accounted for. Trends in emissions are thus subject to periodic revision based on new developments in methodologies and the availability of stack gas sampling data. Plant-specific emissions data are generally obtained

* In June 1988, the Canadian Environmental Protection Act was proclaimed, subsuming the Clean Air Act and several other pieces of environmental protection legislation. The process of bringing the regulations, guidelines, and objectives that were developed under the Clean Air Act (see Chapter 6) into effect under the Canadian Environmental Protection Act is ongoing.

What are air quality objectives?

An air quality objective is a statement of the concentration of an air pollutant and the length of time of exposure to it, which, if not exceeded, affords a specified degree of protection to animals, plants, and materials. Objectives are generally set to cover both short- and long-term exposure to air pollutants. Pollution control agencies routinely monitor the levels of air pollutants and compare the levels with the air quality objectives to determine their progress in securing and maintaining the best possible air quality for the public. The federal government sets national ambient air quality objectives on the basis of recommendations from the Federal–Provincial Advisory Committee on Air Quality. Provincial governments have the option of adopting these either as objectives or as enforceable standards in their jurisdictions.

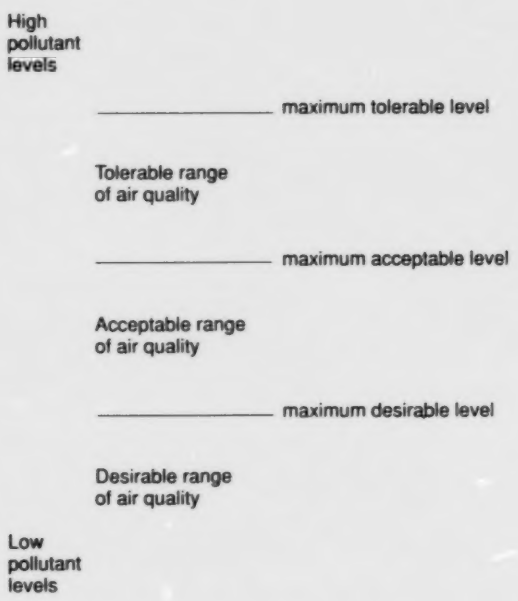
Canada has a unique three-tiered system of national air quality objectives, which arose from the recognition that, in a country as large as Canada, the need for objectives varied across the country. By setting objectives at what are called the maximum tolerable, maximum acceptable, and maximum desirable levels, three ranges of air quality were established to meet these needs (Federal–Provincial Committee on Air Pollution 1976):

- The *maximum desirable level* is the long-term goal for air quality and provides a basis for an antidegradation policy* for unpolluted parts of the country and for the continuing development of control technology.
- The *maximum acceptable level* is intended to provide adequate protection against effects on soil, water, vegetation, materials, animals, visibility, and personal comfort and well-being.
- The *maximum tolerable level* denotes time-based concentrations of air contaminants beyond which, due to a diminishing margin of safety, appropriate action is required without delay to protect the health of the general population.

A review of these objectives and of the need for objectives for other pollutants is under way by the Federal–Provincial Advisory Committee on Air Quality.

These ranges reflect the reality of air quality in Canada. For example, there are parts of the country where the levels of the common air pollutants are extremely low. A reasonable goal for these areas is to maintain air quality within the desirable range and prevent any deterioration in quality. However, there are other more densely populated parts of the country where there are significant emissions of the common air pollutants and where air quality usually falls within the acceptable range. Under these circumstances, for example, a reasonable short-term goal might be to keep within the acceptable range of air quality, avert any trends toward more-polluted air, and work to improve air quality over the long term. When pollutant concentrations are below the maximum acceptable level, there is, by definition, adequate protection for the most sensitive persons and parts of the environment. The tolerable range of air quality was defined to accommodate situations where there was more-severe air pollution, but of an episodic nature, which may require extraordinary control measures. Most provincial governments have adopted the national ambient air quality objectives in whole or in part for use in the provinces. Air quality requirements in Canada are comparable with those in use in many other parts of the world.

Canada's three-tiered system of air quality objectives



* This is a policy of not allowing the quality of unpolluted air to deteriorate even though there might be apparent leeway to do so without demonstrable effects.

Sectors covered in the estimates of emissions

Industrial processes

- Mining and mineral processing
- Iron and steel industries
- Nonferrous smelters: aluminum, copper, lead, zinc, nickel, gold
- Fossil fuel production
- Chemical industries
- Other manufacturers

(excluding heat and power production by these industries)

Fuel combustion in stationary (fixed) sources

- Electric power plants
- Industries
- Commercial enterprises
- Residences (including fuelwood)

Fuel combustion for transportation

- Gasoline-powered vehicles (cars, light- and heavy-duty trucks)
- Diesel-powered vehicles (light- and heavy-duty trucks)
- Other gasoline and diesel engines
- Aircraft
- Boats and ships
- Trains

Solid waste incineration

- Wood waste
- Other waste, such as municipal sludge from sewage treatment

Miscellaneous

- Solvent use, such as in dry cleaning and in surface coatings (e.g., paints, floor coatings)
- Fuel marketing (i.e., transport, storage, and retail distribution)
- Slash burning (i.e., burning wood waste from forestry operations)
- Structural fires

Note: Forest fires are considered to be natural emissions and are not included in the inventory as a source of common air pollutants.

from provincial agencies that acquire the data in order for the plant to receive a provincial permit to operate. Otherwise, emissions data are estimated using standard procedures and "typical" rates of emissions. There is even more uncertainty associated with forecasting emissions. Nevertheless, with care, some useful comparisons of emission levels over time can be made.

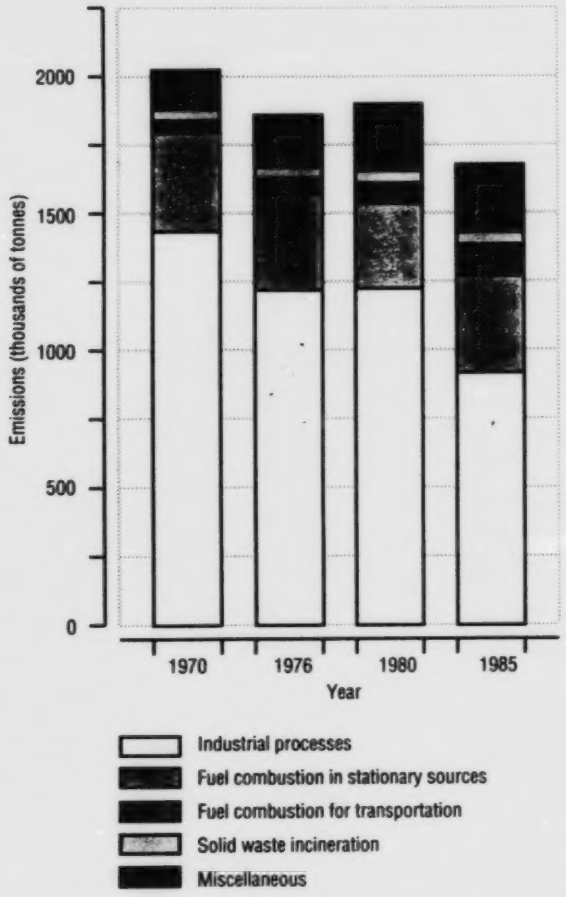
Airborne particulate matter

In preindustrial times, air contained particles of windblown dust, sea salt, forest fire smoke, pollen, and volcanic ash. Now, in the industrial age, thousands more tonnes of particulate matter—from mines, smelters, and pulp mills, from combustion of fuel to produce heat and electricity and to provide power for transportation, from the burning of fuelwood and wood wastes from logging operations, and from waste incineration—are added to this each year in Canada. Estimates of emissions of particulate matter, excluding natural sources such as forest fires, indicate about a 7% reduction between 1970 and 1985 (Figure 6), mainly because of better control of industrial emissions.

Particulate matter in the atmosphere consists of particles ranging in diameter from 0.005 to 100 μm. The adverse health effects induced by exposure to inhaled particulate matter largely depend on its depth of penetration, deposition, and retention in the lung. Those particles that are deposited in the thoracic region of the lung elicit the greatest toxic response. Because it is well established that only particles with a diameter of 10 μm or less enter the thoracic region, the US Environmental Protection Agency (1982) has proposed the term "the PM_{10} fraction" to describe the fraction of the total suspended particulates falling into this size category.

The major health effects that are associated with exposure to suspended particulates are effects on pulmonary function, aggravation of existing pulmonary and cardiovascular disease, effects on mucociliary clearance and other host defence mechanisms, morphological alteration, and mortality (Holland *et al.* 1979; Ericsson and Camner 1983). High mortality rates following exposure to high atmospheric levels of particulates with a concomitant exposure to sulphur oxides were observed following pollution episodes in London, England, and New York in the 1950s and early 1960s (Martin 1964; Greenburg *et al.* 1967). Groups that are at high risk during particulate pollution episodes include the young (school and preschool children), the elderly, those with chronic obstructive cardiovascular disease (heart patients and those with arteriosclerosis), asthmatics, those with influenza or bronchitis, smokers, and those who are oronasal or mouth breathers.

Figure 6
Particulate matter emissions in Canada, 1970–1985



SOURCE: Environment Canada 1986; Vena 1989.

Some other specific concerns that involve particulate matter are as follows:

- *The formation of acid aerosols*—Sulphur dioxide and nitrogen oxide emissions lead to the formation of fine particles composed of sulphates and nitrates. These fine particles can affect lung function and acidify the environment.
- *Reduced visibility*—Polluted air contains gases, particles, and droplets that affect the transmission of light and thus reduce visibility. When light is scattered by particulate matter, the amount of light reaching an observer is reduced. Fine inhalable particles scatter light most efficiently.

Types of particulate matter

For the purpose of formulating the present Canadian air quality objectives, "*suspended particulates*" were considered to include "a wide variety of solid or liquid (aerosol) particles [that] remain suspended in the air and [that can] be drawn into the respiratory passages" (Federal–Provincial Committee on Air Pollution 1976). Excluded was the particulate matter generated by the combustion of wood and fossil fuels, which is known to be composed of or associated with organic substances that are known to have a high toxic potency, including carcinogenicity (e.g., polycyclic aromatic hydrocarbons or PAHs). This class of particulate matter is considered in a separate section (see Chapter 4). In addition, substances with known specific toxic effects, such as arsenic, asbestos, beryllium, PAHs, etc., were specifically excluded when the objectives were developed (Federal–Provincial Committee on Air Pollution 1976).

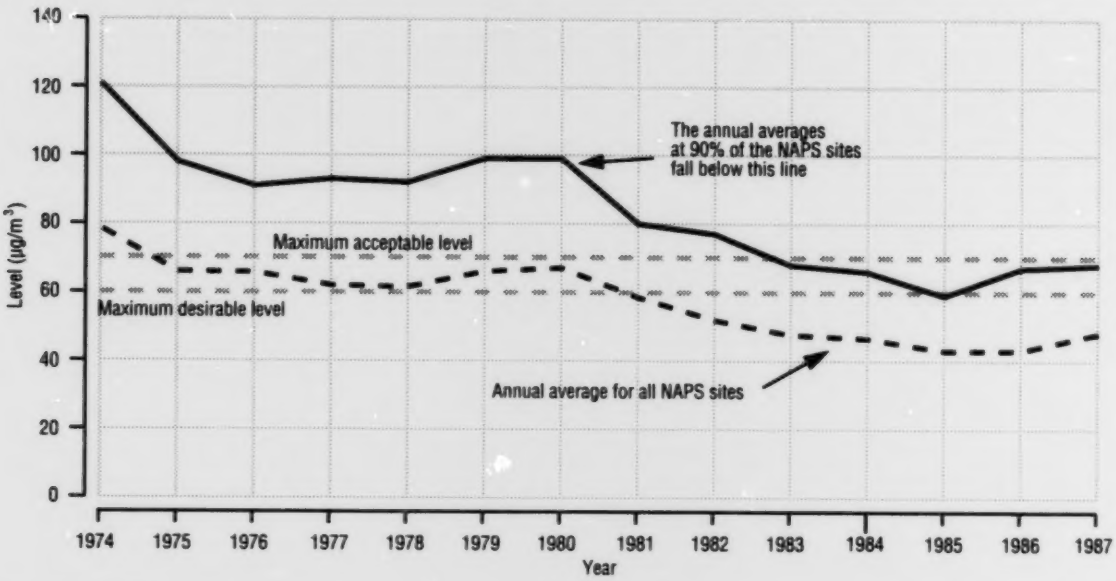
Air quality objectives for suspended particulate matter

Exposure period	Maximum desirable concentration (μg/m³)	Maximum acceptable concentration (μg/m³)	Maximum tolerable concentration (μg/m³)
One hour	—	—	—
24 hours	—	120	400
One year	60	70	—

- *Soiling*—Fine particles (<2.5 μm in diameter) carried by the air are eventually deposited on buildings, automobiles, and clothing. The resultant soiling is aesthetically undesirable.

The present air quality objectives for particulate matter, which were recommended to Environment Canada in the mid-1970s (Federal–Provincial Committee on Air Pollution 1976), were based on the social awareness of pollution (one-year average maximum desirable limit of 60 μg/m³) and the effects on visibility and the aggravation of lower respiratory disease (bronchitis) in children (24-hour average maximum acceptable limit of 120 μg/m³ and a one-year average of 70 μg/m³). These objectives were established when high levels of both particulates and sulphur dioxide were common in urban areas, and they are currently under review by the Federal–Provincial Advisory Committee on Air Quality.

Figure 7
Trends in ambient air levels of total suspended particulate matter in Canada, 1974–1987



SOURCE: Environment Canada 1987, 1988.

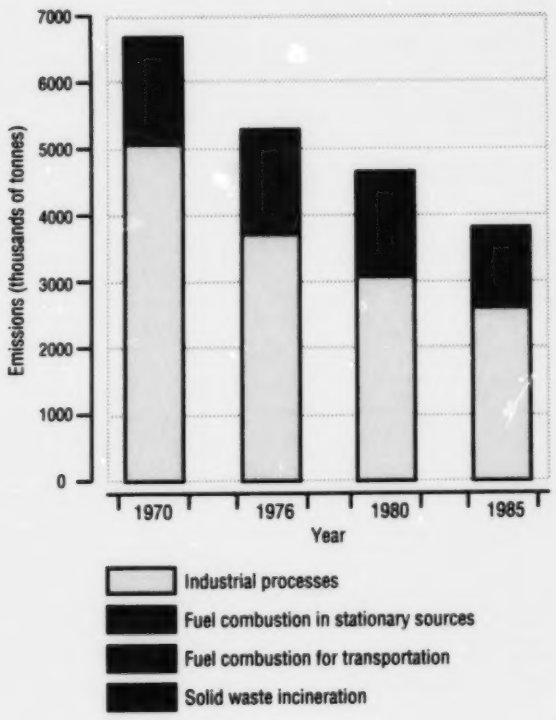
NOTE: Particulate matter is collected over a 24-hour period on every sixth day throughout the year.

Data from Environment Canada indicate that the annual average level of airborne particles at all NAPS monitoring sites decreased by 46% between 1974 and 1986 (Environment Canada 1987, 1988). This significant improvement in urban air quality relative to particulate emissions reductions reflects the fact that most major industrial sources of particulate matter are located outside urban areas. The average levels at more than 90% of the sites were well within the desirable range of air quality in 1986 (Figure 7).

Short-term exposure to high levels of particulate matter continues to be a problem, however. For example, the maximum acceptable level objective for a 24-hour exposure period was exceeded at least 10% of the time at some NAPS sites in Sydney, Rouyn, Windsor, Edmonton, Hamilton, and Calgary. As well, the 24-hour maximum tolerable level ambient air quality objective was exceeded once in 1986 at NAPS monitoring sites in each of Edmonton, Calgary, and Yellowknife. High short-term particulate levels can be attributed in part to natural windblown dust, as well as to construction and industrial activity and the increasing number of motor vehicles on city streets. Over the long term, economic and social development—which has led to the use of cleaner energy sources (e.g., natural gas instead of coal and wood), modernization of older city centres, cleaner streets, more grass and asphalt cover, and the upgrading of industrial and commercial facilities, including installation of equipment to control pollution—appears to be leading to better air quality in urban areas with respect to particulate matter.

Environment Canada has collected inhalable particles (<10 µm in diameter) in 15 Canadian cities since May 1984. Results for the period from May 1984 to December 1987 show that average inhalable particulate levels ranged from 17 µg/m³ in St. John's to 49 µg/m³ at a site in Montreal (Dann 1989*a*). Analysis has shown that the finest of the inhalable particles—those with a diameter less than about 2.5 µm—are different in origin and composition from the coarser particles in the 2.5- to 10-µm-diameter range. The coarse particles are mostly of natural origin (minerals from Earth's crust, sea salt, and plant material), whereas the fine particles consist of lead, sulphates, nitrates, carbon, and a variety of organic compounds, mainly resulting from man-made pollution (State of California Air Resources Board 1982). At eastern Canadian sites, fine particulate matter accounted for more than 60% of the inhalable particles; at

Figure 8
Sulphur dioxide emissions in Canada, 1970–1985



SOURCE: Environment Canada 1986; Vena 1989.

sites in the Prairie provinces, the fine fraction was usually less than 40% of the inhalable particles.

The levels of inhalable particles measured in Canada are below the recently introduced US air quality standards for this size of particle, set at 150 $\mu g/m^3$ for exposure over one hour and 50 $\mu g/m^3$ for exposure over one year (US Environmental Protection Agency 1987). Canadian air quality objectives for inhalable particulate matter are being developed.

Sulphur dioxide

About 70% of total sulphur dioxide emissions in 1985 in Canada came from industrial processes—69% of this was from copper, nickel, lead, zinc, gold, and aluminum production, and a further 21% was from oil and natural gas recovery and processing. Fuel combustion, mainly by power plants and industries, accounted for 28% of total Canadian emissions of sulphur dioxide. Between 1970 and 1985, sulphur dioxide emissions declined by almost 45% (Figure 8), mainly because of modifications to industrial processes and technology, the capture and use of sulphur dioxide to make commercially useful sulphuric acid, and the increased use of low-sulphur fuels (Paine 1989).

Air quality objectives for sulphur dioxide

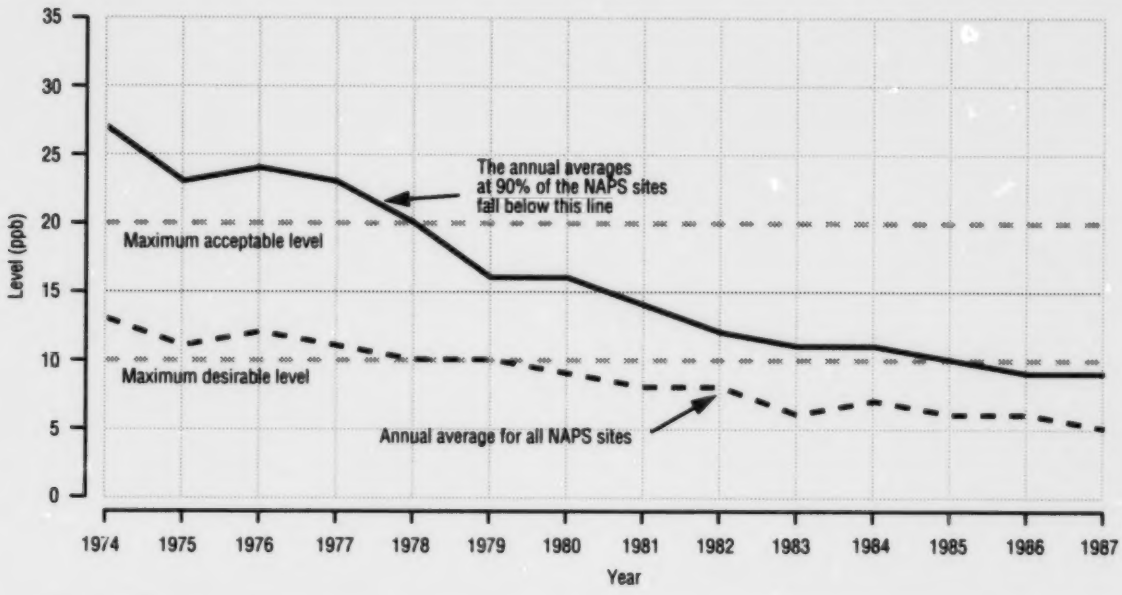
Exposure period	Maximum desirable concentration (ppb)	Maximum acceptable concentration (ppb)	Maximum tolerable concentration (ppb)
One hour	170	340	—
24 hours	60	110	310

Environmental levels of sulphur dioxide can adversely affect both human health and vegetation. In epidemiological and laboratory-controlled human health studies, effects on the lung and the induction of chronic lung disease have been recorded. Although no clear threshold has been identified, short-term exposures to sulphur dioxide at concentrations of up to 1 ppm have not induced severe or irreversible effects; however, significant reductions in lung function have been observed in healthy exercising adults after exposure to this level (Kirkpatrick *et al.* 1982; Stacy *et al.* 1983; Linn *et al.* 1985). Mild respiratory symptoms related to airway dysfunction and transient bronchoconstriction have also been observed in exercising asthmatic subjects (Schachter *et al.* 1984; Witek and Schachter 1985).

In epidemiological studies, short-term exposures to sulphur dioxide that lasted a day or so have been correlated with deaths, although there was concomitant exposure to high particulate levels during these pollution episodes (Martin 1964; Ellison and Waller 1978). Long-term or chronic exposures to levels of up to 50 ppb of sulphur dioxide induced respiratory symptoms and disease (coughs and bronchitis), especially in young children (Dodge 1983) and smokers (Sawicki 1969).

The earliest sign of injury to vegetation is damage to foliage; other plant parts appear to be more resistant. The eastern white pine is a particularly sensitive species, showing signs of acute injury in a matter of hours at a sulphur dioxide concentration in air as low as 25–30 ppb. Many plant species are damaged within hours when exposed to a sulphur dioxide concentration between 100 and 1000 ppb, whereas some hardier plant species show acute damage only above 1 ppm (Federal–Provincial Advisory Committee on Air Quality 1987*a*).

Figure 9
Trends in ambient air levels of sulphur dioxide in Canada, 1974–1987



Source: Environment Canada 1987, 1988.

Long-term injury to vegetation, usually observed as a yellowing of foliage, is generally assessed in terms of the average concentration of sulphur dioxide to which a plant is exposed over the growing season or over a one-year period, because sulphur dioxide concentrations can be quite variable from day to day. The response observed in plants is also strongly influenced by such environmental factors as sun, rain, wind, and drought. Studies of chronic forest damage suggest that effects are prominent when the average sulphur dioxide concentration is about 17 ppb but slight when the concentration is 8 ppb. Lichen species diversity and abundance are affected at 15–20 ppb.

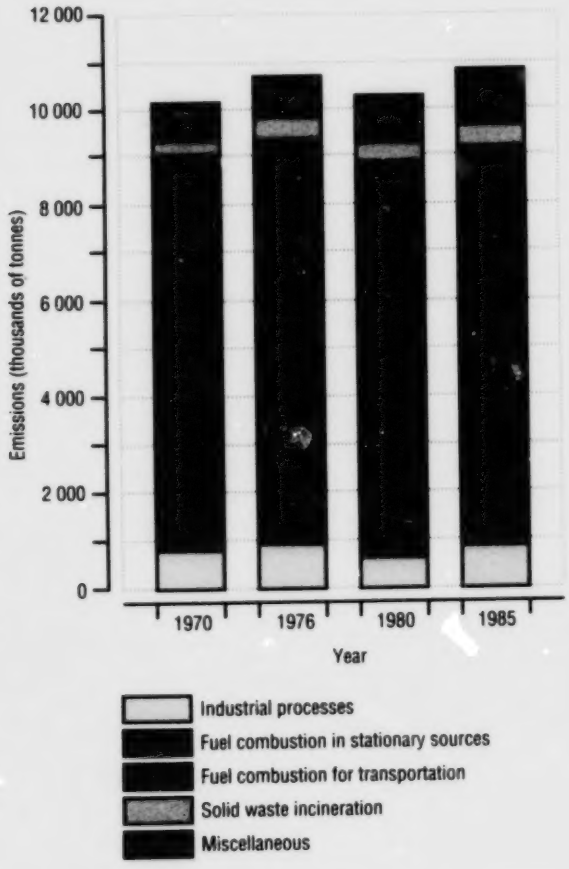
The recommended air quality objectives (Federal–Provincial Committee on Air Pollution 1976) were based on both human health effects and effects on vegetation. The maximum acceptable limits for a one-hour, 24-hour, and annual average were 340, 110, and 20 ppb, respectively; maximum desirable limits were 170, 60, and 10 ppb for the same time periods. These levels were retained following a review of the more recent literature (Federal–Provincial Advisory Committee on Air Quality 1987*a*).

In urban areas of Canada, the annual average level of sulphur dioxide measured at NAPS monitoring sites decreased by 54% between 1974 and 1986—from 13 ppb to 6 ppb—and the annual average levels at 90% of the NAPS monitoring sites are now well below the maximum desirable level annual air quality objective of 10 ppb (Figure 9) (Environment Canada 1987, 1988). In 1986, the one-hour maximum desirable level objective of 170 ppb was met or bettered 99.9% of the time at 93% of the NAPS monitoring sites. Monitoring sites in Montreal, Quebec City, Rouyn, Trois-Rivières, Shawinigan, and Sudbury all recorded hourly average sulphur dioxide concentrations that exceeded the maximum acceptable level one-hour air quality objective of 340 ppb, but in all cases the objective was exceeded less than 1% of the time. At all but the Quebec City, Rouyn, and Shawinigan sites, however, the 24-hour maximum acceptable level air quality objective of 110 ppb was not exceeded in 1986. The 24-hour maximum tolerable level was exceeded 12 times in Quebec City in 1986 (Environment Canada 1988).

Carbon monoxide

Any combustion process where carbon-containing organic material is burned without sufficient oxygen will produce carbon monoxide. Motor vehicles, especially poorly tuned ones, are a major source of carbon monoxide

Figure 10
Carbon monoxide emissions in Canada, 1970–1985



SOURCE: Environment Canada 1986; Vena 1989.

because of the great number on the road at any given time. In fact, more than 66% of the carbon monoxide emitted in Canada in 1985 was from the internal combustion engines of motor vehicles, trains, aircraft, and boats, our principal means of transport (Figure 10).

The amounts of carbon monoxide emitted from industrial processes, from the use of fuel for generating electric power and for heating homes, offices, and commercial and industrial structures, and from burning wood waste and debris from logging operations are each small in comparison with emissions from transportation, but they are nevertheless important. For example, the concentrated emissions of carbon monoxide from home heating with firewood, although less than 6% of total national emissions, are a concern quite distinct from carbon monoxide emissions from motor vehicles, and the potential health effects should not be underestimated.

The more than 10 million gasoline-powered automobiles and trucks that travelled Canada's roads and highways in 1985 emitted about 5.8 million tonnes of carbon monoxide, marginally less than the amount emitted in the early 1970s. Considering that in 1985 there were more than four million additional motor vehicles in use than there were in 1970 (Figure 11)—i.e., about 70% more—achieving a reduction in total emissions over this period is significant. Most of the credit must be attributed to the use of catalytic converters in order to meet federal motor vehicle emissions standards introduced in 1971 (see Chapter 6). These standards were tightened in September 1987, which is expected to lead to even greater emissions reductions.

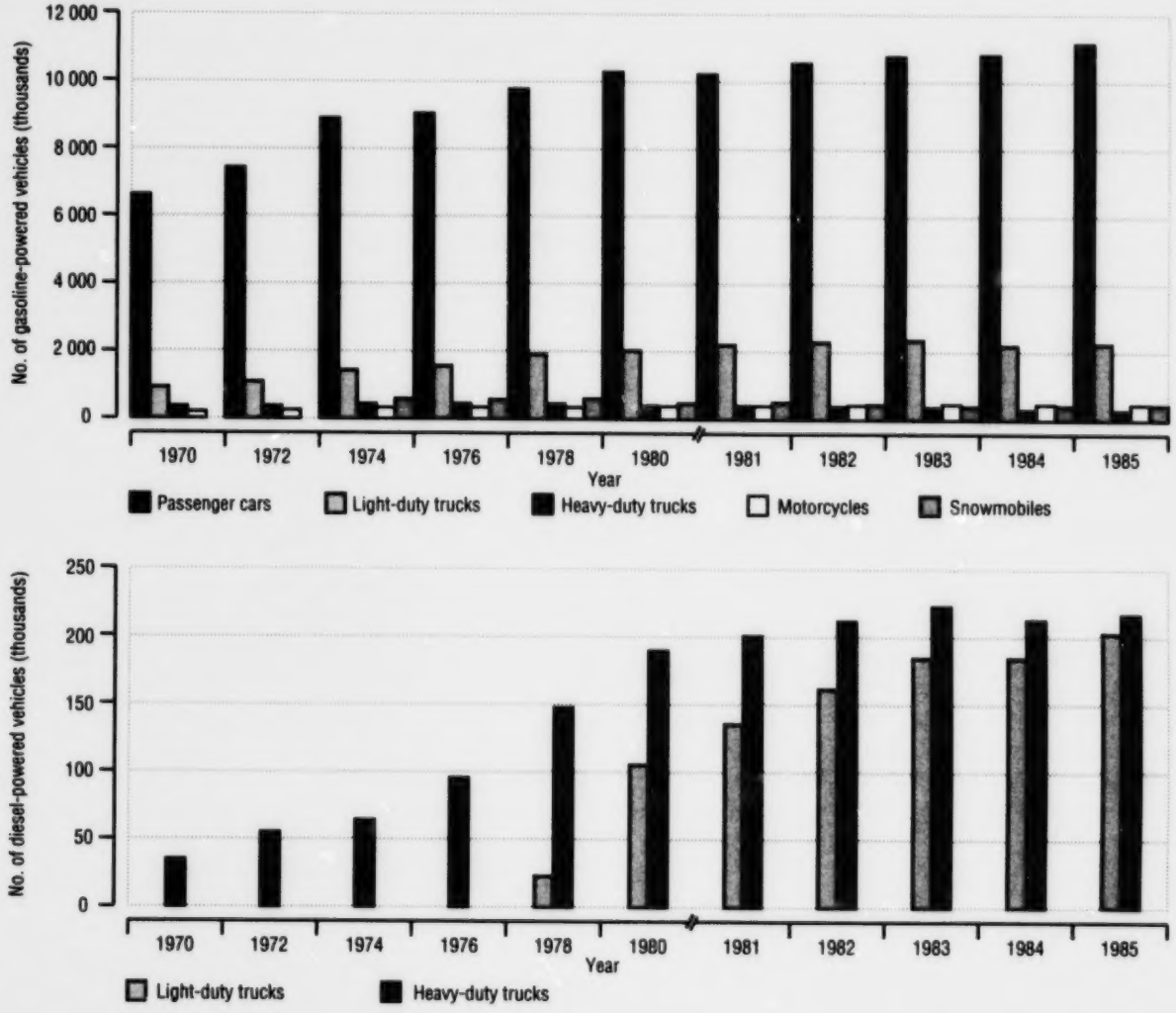
The toxic effects of carbon monoxide are due to its preferential combination with the heme component of red blood cells to form carboxyhemoglobin, which reduces the capacity of the red blood cells to carry oxygen to the tissues. Because humans produce carbon monoxide in their bodies as a consequence of normal respiration, levels of carboxyhemoglobin of about 0.05–1.0% are found in healthy humans. In humans with hemolytic disease, the level is normally higher. Physiological effects are known to occur when carboxyhemoglobin levels reach 2.5–3.0%, and this induces a deficiency of oxygen in the tissues, increased oxygen debt, and even fatal myocardial infarction at exposures of about 5000 ppm for a few minutes or chronic exposure to about 14 ppm (Chevalier *et al.* 1966; Smith 1968; Cohen *et al.* 1969; Brody and Coburn 1971).

Chronic exposures of animals (rats and mice) to carbon monoxide have revealed other physiological and behavioural changes. These include an impairment in time discrimination (Beard and Wertheim 1967) and a consistent trace metal loss (Mazaleski *et al.* 1970), but further work on this aspect is needed before firm conclusions can be drawn.

Special groups at risk when exposed to relatively high levels of carbon monoxide (>2.0%) include those with heart function and blood circulation problems, smokers, anemics, and, possibly, those living at high altitudes.

Only one-hour and eight-hour objectives were recommended to Environment Canada by the Federal–Provincial Committee on Air Pollution (1976); these were 13 and 5 ppm for the desirable levels, and 30 and 13 ppm for the acceptable levels, respectively. These recommendations remained unchanged in the more recent appraisal (Federal–Provincial Advisory Committee on Air Quality 1987*b*), except for the eight-hour acceptable level, for which 11 ppm was recommended. Environment Canada is considering this recommended change.

Figure 11
Number of gasoline- and diesel-powered vehicles in Canada, 1970–1985



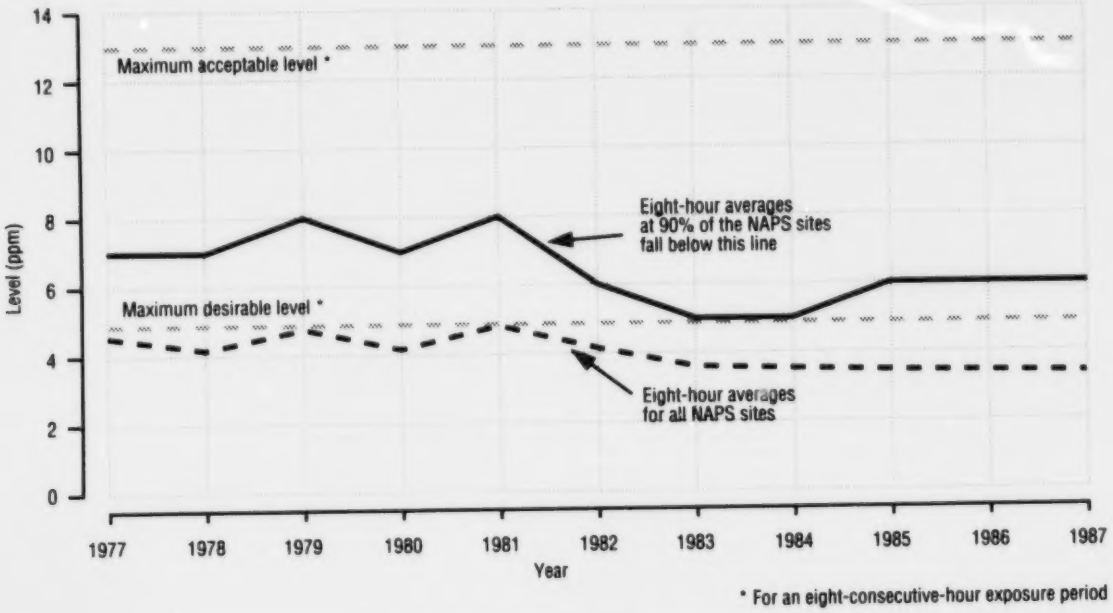
SOURCE: Environment Canada, Transportation Systems Division, Ottawa.

Air quality objectives for carbon monoxide

Exposure period	Maximum desirable concentration (ppm)	Maximum acceptable concentration (ppm)	Maximum tolerable concentration (ppm)
One hour	13	30	—
Eight hours	5	13	17

Monitoring of air quality in Canada through the NAPS network shows that the eight-hour average carbon monoxide levels decreased about 23%, from 4.4 ppm in 1977 to 3.4 ppm in 1986 (Figure 12) (Environment Canada 1987, 1988). Even more encouraging is the general decline noted in the magnitude of the highest concentrations registered across the country. Monitoring stations in Toronto and Calgary reported the highest carbon monoxide levels in 1986,

Figure 12
Trends in ambient air levels of carbon monoxide in Canada, 1977–1987


Maximum acceptable level *
Eight-hour averages at 90% of the NAPS sites fall below this line
Maximum desirable level *
Eight-hour averages for all NAPS sites
Level (ppm)
Year
* For an eight-consecutive-hour exposure period

SOURCE: Environment Canada 1987, 1988.

although they exceeded the eight-hour maximum acceptable level air quality objectives less than 1% of the time. The eight-hour maximum tolerable level was exceeded seven times at the Yonge Street monitoring station in Toronto in 1986 (Environment Canada 1988). Nevertheless, even these sites met the air quality objectives 99% of the time.

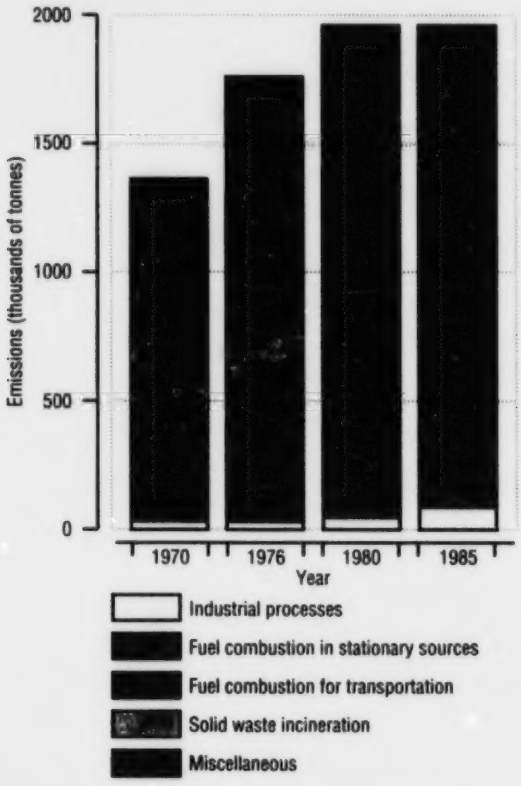
Nitrogen oxides

Oxides of nitrogen is the term given to a group of gases that are composed only of oxygen and nitrogen. Nitric oxide (NO) and nitrogen dioxide (NO_2) are the two most abundant oxides of nitrogen in polluted atmospheres. Because air contains 78% nitrogen and 21% oxygen, oxides of nitrogen are readily formed by the direct reaction of these elements in high-temperature combustion processes, natural biogenic processes—mainly bacterial action in the soil—lightning, volcanic action, and forest fires. Combustion processes produce mainly nitric oxide, but the easy conversion to nitrogen dioxide in the atmosphere is quite rapid and therefore makes nitrogen dioxide the pollutant of concern as far as effects on human health and the environment are concerned. Other oxides of nitrogen, such as nitrous oxide (N_2O), nitrogen tetroxide (N_2O_4), dinitrogen trioxide (N_2O_3), and nitrogen pentoxide (N_2O_5), are also formed, but their concentrations are small. Nitrous oxide, however, has been implicated in global warming (see Chapter 5).

The high-temperature combustion of fuel for transportation accounted for almost 64% of total emissions in 1985. More than 30% of the emissions of oxides of nitrogen in Canada in 1985 were derived from fuel use in homes, businesses, factories, and power plants. Emissions have risen by about 43% between 1970 and 1985, largely because of an increase in energy demand for transportation (Figure 13).

The federal government has signed an international protocol to limit total emissions of oxides of nitrogen to the 1987 level by 31 December 1994. Emissions of oxides of nitrogen in Canada have been forecast to the year 2005: a 6% increase between 1985 and 2005 is projected (Figure 14). The introduction of catalytic converters in the 1970s

Figure 13
Oxides of nitrogen emissions in Canada, 1970–1985



SOURCE: Environment Canada 1986; Vena 1989.

slowed the rate of increase of motor vehicle emissions substantially, but emissions from transportation are nevertheless predicted to continue to rise as a result of the increased number of motor vehicles on the road. Tighter emission controls on light-duty motor vehicles manufactured as of 1 September 1987 and controls on heavy-duty motor vehicles manufactured as of 1 January 1988 will keep these emission levels at close to 1985 levels through to 1995, beyond which total emissions are expected to increase as a result of increased use of both industrial and transportation fuel (see Chapter 6). The federal government is analyzing ways to control emissions of nitrogen oxides from those internal combustion engines that are not regulated at present, and to further control transportation emissions (Transport Canada 1989; Transport Canada/Environment Canada 1989) to meet the terms of the international protocol.

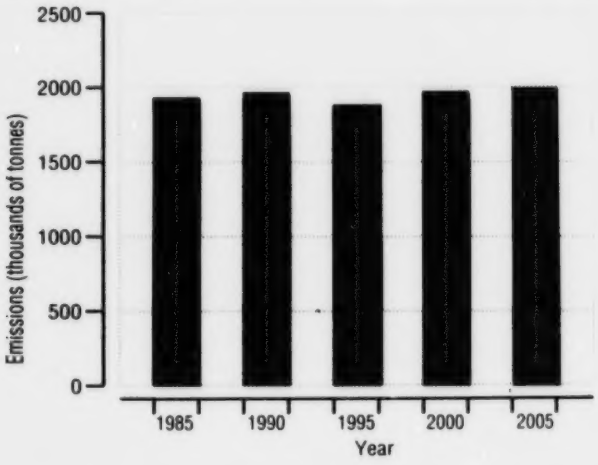
The fate of oxides of nitrogen in the atmosphere

- The ways in which oxides of nitrogen react in the atmosphere and ultimately are returned to land and water are complex.
- The average times that nitric oxide and nitrogen dioxide remain in the atmosphere have been estimated at four and three days, respectively.
- Any nitric oxide that is released to the atmosphere in high concentrations is usually oxidized rapidly to nitrogen dioxide, which is both an air pollutant of concern in its own right and a substance that can be oxidized further, ultimately forming nitric acid or nitrate salts such as ammonium nitrate or reacting with volatile organic compounds in the presence of sunlight to form ground-level ozone.
- Oxides of nitrogen may cause local air pollution problems, but, because they can remain airborne for several days, especially when released from tall stacks, they and their reaction products (salts, acids, and ground-level ozone) can be carried by winds over long distances, often across international boundaries.
- Oxides of nitrogen and their reaction products may be carried thousands of kilometres from their origin; in eastern North America, the net transport is in a northeasterly direction, including transport across the US–Canada border.

Studies in animals indicate that exposure to nitrogen dioxide at a level of about 500 ppb for four hours reduces host resistance to bacterial and viral infection (Ehrlich and Henry 1968). Alterations in pulmonary function and in morphological and biochemical parameters also occur (Freeman *et al.* 1966; Buell 1970; Gregory *et al.* 1983).

Clinical studies in humans reveal odour perception and an impairment in "dark adaptation" (a test of one's ability to adapt to dim illumination after looking at a bright light) at levels between 100 and 200 ppb for a few minutes (Henschler 1960; Salamberidze 1967). Symptoms of irritation and effects on pulmonary function are known to occur at levels as low as 100 ppb, especially in asthmatics and bronchitics (Kerr *et al.* 1979). Epidemiological studies

Figure 14
Forecasted emissions of oxides of nitrogen in Canada to the year 2005



SOURCE: Vena 1989.

Air quality objectives for nitrogen dioxide

Exposure period	Maximum desirable concentration (ppb)	Maximum acceptable concentration (ppb)	Maximum tolerable concentration (ppb)
One hour	—	210	530
24 hours	—	110	160
One year	30	50	—

show that children are especially susceptible to the effects, such as bronchitis and pulmonary function changes, induced by chronic exposure to nitrogen dioxide concentrations of about 100 ppb (Shy *et al.* 1970; Pearlman *et al.* 1971).

Nitrogen dioxide also suppresses the growth of vegetation (Thompson *et al.* 1970; Ashenden and Mansfield 1978) and causes the corrosion of metals, the fading of fabric dyes, and the degradation of textile fibres, rubber products, and polyurethanes (National Academy of Sciences 1979). Abnormal effects on materials and adverse effects on vegetation are observed at higher exposure levels than those that cause adverse effects on human health.

The recommended air quality objectives (Federal–Provincial Committee on Air Pollution 1976) are therefore based on the protection of human health. The one-hour, 24-hour, and annual average maximum acceptable levels are 210, 110, and 50 ppb, respectively. An annual average of 30 ppb is recommended as a maximum desirable level. These objectives are currently under review.

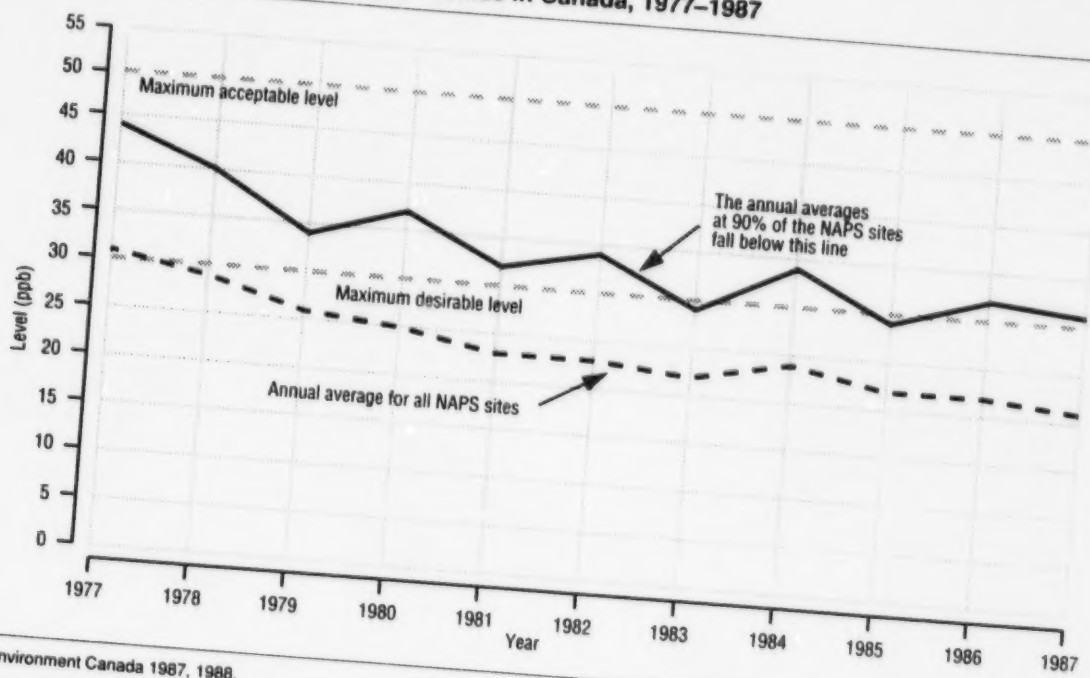
Since 1978, annual mean nitrogen dioxide levels in Canada measured by the NAPS network have been consistently below the maximum desirable level air quality objective of 30 ppb, despite an increase in total emissions in Canada, and showed a decline of about 25% between 1977 and 1986 (Figure 15) (Environment Canada 1987). This decline in urban nitrogen dioxide levels in spite of rising oxides of nitrogen emissions nationally is explained by the significant decrease in oxides of nitrogen emissions from transportation sources in the late 1970s and early 1980s. In 1986, the annual average nitrogen dioxide level at more than 90% of the NAPS monitoring stations was below 30 ppb, and there were no exceedances of the maximum tolerable level ambient air quality objectives (Environment Canada 1986, 1988). The maximum acceptable level objective for one hour was exceeded twice in each of Calgary and Sault Ste. Marie, and that for 24 hours was exceeded 29 times at a NAPS site in Montreal.

Ground-level ozone

The ozone found in the troposphere is not emitted as a pollutant but is formed through a complex series of reactions involving oxides of nitrogen and volatile organic compounds. The reactions are driven by energy provided by ultraviolet radiation from the sun. In the absence of pollution (Figure 16*a*), ozone is produced and consumed in a cyclical reaction involving natural nitrogen oxides, which results in fairly constant ozone concentrations throughout the troposphere. In polluted air, which contains high concentrations of nitrogen oxides and volatile organic compounds, the natural equilibrium between natural oxides of nitrogen and ozone is upset. The volatile organic compounds react with the nitric oxide faster than the ozone does, leading to high ozone levels. This occurs mainly in the lower 1.5–2 km of the troposphere (van Hamm 1988) (Figure 16*b*); therefore, this ozone is often referred to as "*ground-level ozone*."

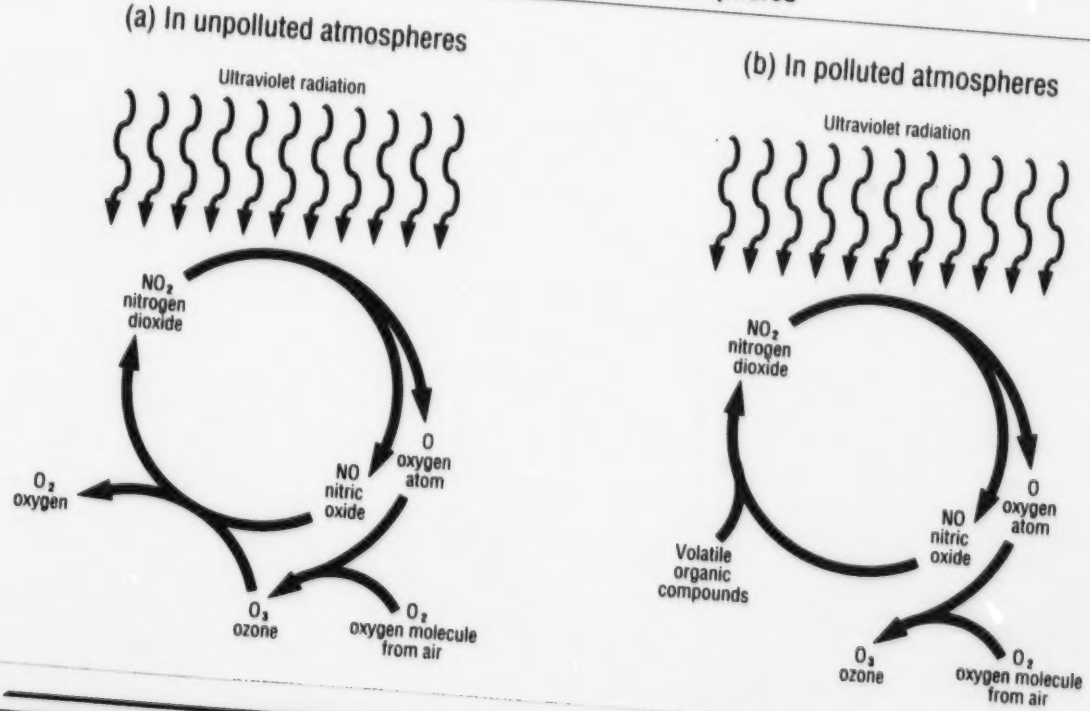
Animal studies show that short-term (seven days continuous) or repeated exposure of rats to about 200 ppb of ozone results in irreversible damage to the entire respiratory tract (Plopper *et al.* 1979; Barry *et al.* 1983). The degree of injury to sensitive tissues is related to the concentration of ozone rather than to the duration of exposure. Altered macrophage activity and immune function are also responses elicited by ozone exposure that could result in an increased host susceptibility to infection. Such an event is

Figure 15
Trends in ambient air levels of nitrogen dioxide in Canada, 1977–1987



SOURCE: Environment Canada 1987, 1988.

Figure 16
Tropospheric ozone formation in unpolluted and polluted atmospheres



Tropospheric ozone in the Greater Vancouver area and the Fraser Valley

Historically, high levels of tropospheric ozone have formed in the Greater Vancouver area and the lower Fraser Valley region in British Columbia. The geography of this region, meteorological conditions related to sea breezes, and local emissions of oxides of nitrogen and volatile organic compounds together have provided ideal conditions for ozone formation. The importance of medium- and long-range transboundary flow of ozone precursor pollutants into the region is not known.

Between 1979 and 1982, the one-hour maximum acceptable level air quality objective of 82 ppb ozone was frequently exceeded. Since then, however, monitoring stations in the Greater Vancouver area have registered a largely unexplained 32% reduction in the average of the maximum ozone levels recorded at all stations. Most of the reduction occurred between 1981 and 1982, and in 1987. From 1979 to 1986, there was an estimated 11.5% decrease in hydrocarbon emissions from highway vehicles, whereas oxides of nitrogen decreased by about 2% between 1982 and 1987. The substantial ground-level ozone reductions are not easily explained by these small reductions in hydrocarbon and oxides of nitrogen emissions. One theory is that changes in hydrocarbon emissions from motor vehicles may be greater than estimated, and that the reactivity of hydrocarbon emissions may have decreased, lengthening the time taken for ozone formation. Changes in meteorological conditions could also explain the lower ozone levels of recent years. The ambient air monitoring network has been enhanced to determine if the ozone precursors are being transported from the urban centre to the Fraser Valley before they completely react to form ozone. Also, two sites have been equipped to monitor volatile organic compounds for the first time. A comprehensive inventory of sources and emissions of air pollutants has been completed (Greater Vancouver Regional District 1988).

Long-term meteorological records indicate that about 40 to 50 times each year, ground-level ozone concentrations can be expected to be above 82 ppb for at least three consecutive hours (Wilson *et al.* 1984). Within the Greater Vancouver Regional District, monitoring data show that the highest ground-level ozone concentrations are registered in the eastern part of the urban area; this, together with wind data, suggests that the transport of ground-level ozone farther east into the Fraser Valley is likely.

A preliminary economic analysis of ground-level ozone damage to agricultural crops has been undertaken by the BC Ministry of Environment, the BC Ministry of Agriculture and Fisheries, and other agencies. The total value of vegetables, tree fruits, and berries produced in the Lower Fraser Valley was about $120 million in 1983. The damage assessment based on these crops, as well as forage and grain, is estimated at $9 million (Wilson *et al.* 1984).

known to occur in mice when exposed to less than 100 ppb of ozone for three hours (Miller *et al.* 1978).

In humans, studies of repeated short-term or acute exposures to about 100 ppb of ozone show that the developing lung in infants and children is particularly susceptible to damage, and this can lead to the eventual development of chronic pulmonary disease (Lippmann *et al.* 1983). Smokers, asthmatics, and individuals with chronic obstructive pulmonary disease—previously considered as potentially sensitive subgroups—do not appear to be more sensitive than healthy adults (Lebowitz *et al.* 1983). The principal effect noted in human studies is a significant decrease in pulmonary function.

Ozone exposure also affects vegetation significantly. Damage to tobacco crops in southwestern Ontario (MacDowall *et al.* 1963), trees (Linzon 1966), various vegetable crops (Heagle *et al.* 1979), and herbaceous ornamental plants (Adedipe *et al.* 1972) is well documented. Annual yield losses for selected Ontario crops have recently been estimated to range from 1 to 12% when the seasonal average ozone concentration ranged from 40 to 50 ppb. The value of crop damage in Ontario in 1980 was estimated at $23 million and in the United States at as much as $2 billion (Heck *et al.* 1982) if levels of ozone met the current one-hour US Environmental Protection Agency air quality standard of 120 ppb. High short-term ozone levels are of principal significance with respect to human health impact, whereas average levels over the growing season are more significant with respect to vegetation damage.

Canada's air quality objectives for ozone are among the most stringent in the world. It should be noted that the national ambient air quality objectives for ozone are designated as applicable to oxidants (ozone) because polluted air contains oxidants other than ozone, such as nitrogen dioxide and peroxyacetyl nitrate. The latter, in particular, is known

Air quality objectives for oxidants (ozone)

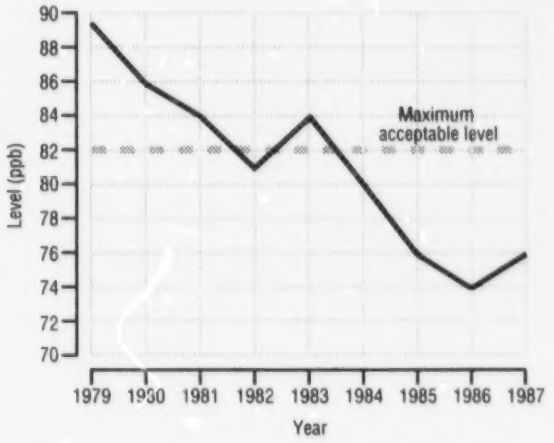
Exposure period	Maximum desirable concentration (ppb)	Maximum acceptable concentration (ppb)	Maximum tolerable concentration (ppb)
One hour	50	82	150
24 hours	15	25	—
One year	—	15	—

to cause specific and characteristic injury to vegetation (Stephens *et al.* 1961). Ozone, however, is the major oxidant of concern. The maximum desirable levels for oxidants (ozone) are 50 and 15 ppb for one-hour and 24-hour averages, respectively. The maximum acceptable levels are 82, 25, and 15 ppb for the one-hour, 24-hour, and one-year averages, respectively, based on recommendations from the Federal–Provincial Committee on Air Pollution (1976). The objectives, particularly the desirable limits, were largely based on vegetation effects, because crop damage occurred at levels well below those that induced adverse human health effects. The objectives are currently under review.

High ozone levels frequently occur in, and several hundred kilometres downwind of, highly populated areas of the country where motor vehicles, combustion processes, and industrial emissions are major sources of the oxides of nitrogen and volatile organic compounds necessary for ozone production. The trend in the average of the high ozone levels recorded between 1979 and 1987 at 45 monitoring sites in the NAPS network is shown in Figure 17. The annual average of these high levels decreased by 15% (from 89 to 76 ppb) during this period (Dann 1989*b*). The general downward trend was interrupted in 1983 and 1987 because of more frequent high ozone levels at eastern Canadian monitoring sites. There are indications from preliminary data that the 1988 average high ozone level was greater than the 1987 level.

Ground-level ozone levels are often high enough to exceed Canada's national air quality objectives, especially during summer when stagnant air traps pollutants for several days over broad regions of the country. In 1986, every city in the NAPS network exceeded one or more of the maximum acceptable level objectives for ozone at some time. The average number of hours that ozone levels exceeded the Canadian maximum acceptable air quality objective of 82 ppb at the 45 NAPS monitoring sites shown in Figure 17 decreased between 1979 and 1986 by 41%, from 24.8 hours per year to 14.6 hours per year (Figure 18). A study of the

Figure 17
Decline in the annual average of high ozone levels in Canada



SOURCE: Dann 1989*b*.

Figure 18
Decline in the number of hours that the one-hour air quality objective for ozone (82 ppb) was exceeded in Canada, 1979–1987

SOURCE: Dann 1989*b*.

The formation and role of ozone in the atmosphere

An easily misunderstood aspect of air pollution and atmospheric change is the formation and role of ozone, which differ depending on where in the atmosphere the ozone is formed and whether or not pollutants are present.

Ozone in the troposphere	Ozone in the stratosphere
• Located within 11 km of Earth's surface	• Located between 11 and 47 km above Earth's surface
• Formed in two ways: (1) from oxygen by lightning in small amounts (natural background levels) in the troposphere; and (2) by photochemical reactions in large amounts in the lower 1.5–2 km of the troposphere when levels of pollutants are high in the summer (referred to as *ground-level* ozone)	• Formed in the stratosphere through the action of ultraviolet radiation from the sun on stratospheric oxygen
• Acts at natural background levels as an essential reactant in beneficial tropospheric chemical reactions	• Acts along with stratospheric oxygen to reduce the amount of ultraviolet radiation reaching Earth's surface
• May damage human health, vegetation, and materials when present above background levels	• Is being depleted by pollution, allowing more ultraviolet radiation to reach Earth

relative frequency of ozone levels above 82 ppb between 1982 and 1986 in major Canadian cities in the NAPS network indicates that the highest frequency occurred between Windsor, Ontario, and Quebec City, Quebec, and in the Greater Vancouver Regional District (Figure 19). In 1988, the one-hour maximum acceptable level was reported to have been exceeded on 157 occasions in the Toronto suburb of North York, 122 times in Oakville, 189 times in Windsor, and 149 times in London. There were no exceedances of the maximum tolerable level ambient air quality objectives in 1986.

Table 4
Average ozone concentrations at rural and suburban sites during the growing season[a]

Location	Site type	Mean ozone concentration (ppb)
Dartmouth, NS	Suburban	37
Kejimkujik, NS	Rural	31
St. Étienne, Que.	Rural	39
St. Zephirin, Que.	Rural	41
St. Barnabé, Que.	Rural	39
Dorset, Ont.	Rural	40
Stouffville, Ont.	Suburban	41
Simcoe, Ont.	Rural	49
Madaumin, Ont.	Rural	48
Huron Park, Ont.	Rural	45
Guelph, Ont.	Suburban	44
Winnipeg, Man.	Suburban	29
Saskatoon, Sask.	Suburban	25
Edmonton, Alta.	Suburban	35
Calgary, Alta.	Suburban	37
Fortress Mtn., Alta.	Rural	>43
Birch Mtn., Alta.[b]	Rural	36
Kelowna, BC	Suburban	36
Abbotsford, BC	Rural	33
Seymour Lake, BC	Rural	36
Surrey, BC	Rural	33

SOURCE: Dann 1989*b*

[a] Between 09:00 and 16:00, June–August 1987.
[b] 1981 to 1983.

The average ground-level ozone concentration measured during June, July, and August (key growing months for vegetation) between 09:00 and 16:00 (hours of high photosynthetic activity) has been proposed as an indicator of the potential for ground-level ozone to damage crops. An average concentration below 32 ppb during this period, referred to as the growing season, has been proposed as an air quality objective to prevent injury to sensitive vegetation. Data from rural and suburban monitoring sites in Canada in 1987 indicate that this level is exceeded at most sites (Table 4). Ground-level ozone at rural sites may originate from nearby or distant urban areas, from natural and man-made rural sources of oxides of nitrogen and volatile organic compounds, or from transport of ozone from other parts of the troposphere.

Figure 19
Number of days per year with ozone levels in excess of the one-hour air quality objective of 82 ppb

SOURCE: Dann 1989*b*.

Hydrocarbons

Total emissions of hydrocarbons in Canada increased by about 15% between 1970 and 1985 (Figure 20). More than 66% of these emissions in 1985 were from transportation and industrial processes. Emissions from transportation, because they are controlled, dropped about 20% between 1970 and 1985; the largely uncontrolled emissions from industrial processes increased by 60%, and those from fuel marketing, dry cleaning, surface coating, and burning wood waste from forestry operations increased by 38%. Emissions from fuel combustion appear, from Figure 20, to have increased about fourfold; however, the increase is due to changes in the way that emissions were calculated for 1985, and 1985 and later values should not be compared with values from earlier years.

Ambient air levels and trends for hydrocarbons are not measured routinely because the numbers and variety of hydrocarbons present in the air at any time—several thousand individual compounds, in some instances—make interpretation of the results, in terms of protecting human health and the environment, essentially impossible. Usually, individual compounds or some fraction of the total hydrocarbon content of the air is measured because it is of specific interest: for example, volatile organic compounds (VOCs) are of interest because they promote ground-level ozone formation, benzene because it is a known cancer-causing agent, and methane because it contributes to global warming through the greenhouse effect. These and other hydrocarbon-related air pollution problems are discussed elsewhere in this report (see Chapters 4 and 5).

Gasoline volatility

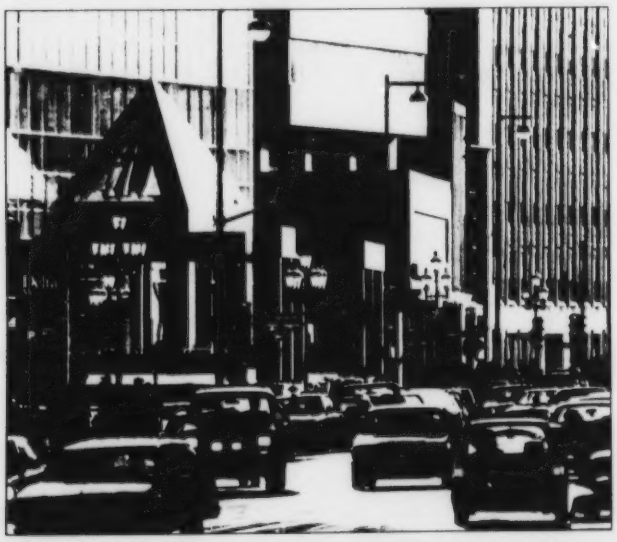
One desirable property of gasoline is that it mixes easily and completely with air to form combustible mixtures over a range of temperatures, so that motor vehicles start, warm up, and run smoothly. The composition of the gasoline determines this ability and, therefore, is an important determinant of gasoline quality. However, because Canadian gasolines are so volatile, the production, distribution, and use of gasoline in Canada account for over 50% of the total emissions of volatile organic compounds to the atmosphere, exclusive of natural sources. Volatile organic compounds from gasoline evaporation promote ground-level ozone production and may be hazardous to human health if inhaled.

There has been a trend since the 1970s toward the production of gasoline with higher volatility. One way to increase the volatility of gasoline is to increase the butane content during the refining process. Reducing fuel volatility, however, is one means of reducing gasoline evaporative emissions from carburetors and gas tanks and losses during refuelling of motor vehicles. The latter account for about 40% of volatile organic compound emissions from motor vehicles; the remaining 60% of volatile organic compound emissions from motor vehicles are from unburned gasoline released in exhaust. Federal and provincial environment ministers have agreed to take steps to cap or reduce gasoline volatility in Canada based on the need to control ground-level ozone in different parts of the country (CCREM 1989).

There are other factors that influence fuel volatility, with environmental implications. The desire to find substitutes for the use of lead as an octane-boosting additive in gasoline and to find less costly alternatives to petroleum-based automotive fuel has prompted gasoline retailers to test alcohol–gasoline blends in the North American marketplace. The direct addition of alcohols to gasoline increases the volatility of the mixture. These blends can be made to match closely the volatility characteristics of gasoline by removing some of the more volatile components of gasoline before blending, which is a more costly process.

There are both positive and negative environmental aspects to the use of alcohol-blended fuels. Combustion of alcohol–gasoline blends produces less carbon monoxide and volatile organic compounds in exhaust gases from automobiles equipped with comparable exhaust emissions control devices than does combustion of gasoline of similar volatility. Aldehyde and unburned alcohol emissions are higher from blends, whereas emissions of oxides of nitrogen are comparable for both types of fuel.

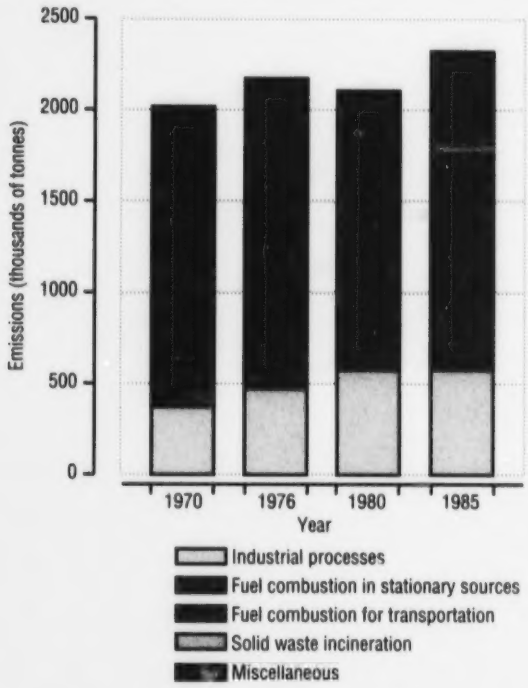
Current evidence suggests that methanol–gasoline blends may have less ground-level ozone-forming potential than pure gasoline, but this is offset by an increase in aldehyde emissions. Aldehydes have high potential to form ground-level ozone.



Gilles Delisle

Rush-hour traffic in downtown Montreal: Hydrocarbon emissions from fuel combustion

Figure 20
Hydrocarbon emissions in Canada, 1970–1985



SOURCE: Environment Canada 1986; Vena 1989.

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Chapter 4

Approaches for studying toxic air pollutants

Introduction

There are many hundreds of toxic air pollutants, and they may enter the environment in many ways. A recent study in the United States has shown that the amounts and sources of toxic air pollutants can be quite variable geographically—from city to city and from neighbourhood to neighbourhood—and are strongly influenced by local, widespread sources, such as motor vehicles, woodstoves, combustion of oil and gas, metallurgical industries, chemical production and manufacturing, gasoline marketing, solvent use, and waste oil disposal (Haemisegger *et al.* 1985). Major industrial sources were also found to be responsible for or to contribute to certain toxic air pollutant problems. Overall, however, the database was found to be inadequate to allow an accurate characterization of most local problems. The authors of the study noted that indoor sources of toxic air pollutants make an important contribution to the risk of ill health. Toxic waste storage and disposal sites and consumer products are additional sources of toxic air pollutants.

The similarities between Canada and the United States—e.g., the size of their major cities, the lifestyles and occupations of their citizens, the nature of their manufacturing and service industries—suggest that their toxic air pollutant problems are likely to be similar. There is evidence to support this contention, although there has not been a parallel study performed in Canada to evaluate the full problem nationally. For example, both countries have established national emissions standards for such pollutants as asbestos, mercury, vinyl chloride, and lead from industrial sources. Both countries have acted to reduce the lead content of gasoline; to eliminate the production, importation, and use of polychlorinated biphenyls (PCBs); and to tighten pesticide registration requirements, ban certain pesticides, and implement measures to educate and protect pesticide users. However, the emissions of many hundreds of other toxic air pollutants are unregulated and uncontrolled, and there is evidence from monitoring studies that the levels of toxic air pollutants in ambient air are similar in both countries. Emissions associated with the use of the automobile may be a significant source (Carhart and Walsh 1988).

Because there are hundreds of toxic air pollutants, we cannot possibly deal with them all here. Instead, the sections that follow show examples of the ways that toxic air pollutant problems are being addressed:

(1) by focusing on a chemical, such as lead;

(2) by focusing on a class of chemicals, such as volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs);

(3) by focusing on a specific activity, such as wood burning; or

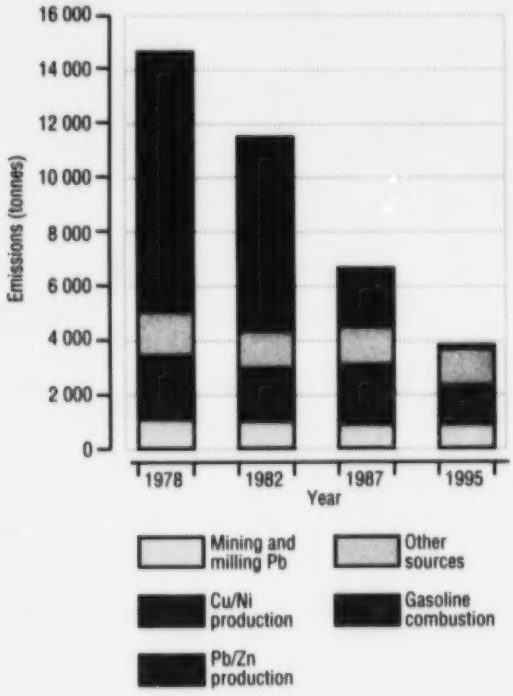
(4) by focusing on a geographical area, such as the Junction Triangle area of Toronto, a small, industrialized urban area with local pollution problems.

Dealing with toxic air pollutants presents one of the great challenges for the future. Many of the substances classified as toxic air pollutants have also been found in surface water, sediment, drinking water, and food, some of which were undoubtedly contaminated by pollutants that were originally released to the environment through the air. The contribution to total exposure of the public to these pollutants from both outdoor and indoor sources must also be considered (Smith 1988). The studies described below provide useful information on the sources and levels of some toxic air pollutants in the outdoor environment.

Single chemical—Lead

Lead is a metal that has been widely used for many purposes for over 4000 years, mainly because of its low melting point, high density, and resistance to corrosion. Some of the most common current uses of lead are in piping, solder, roofing, storage batteries, paint, corrosion-resistant containers, weights, gunshot, and crystal. For close to 70 years, organic lead compounds have been used as octane boosters in gasoline. In recent years, the most significant emission sources to the atmosphere have been gasoline combustion in motor vehicles and industrial sources—mining and milling of lead, copper, and nickel, and iron and steel production. The picture is expected to change by 1995 (Figure 21).

Figure 21
Distribution of lead emissions in Canada, 1978–1995



SOURCE: Environment Canada 1983, 1985; Jaques 1988a.

Because lead is often used in a fairly pure form, recycling of lead is economically feasible. Although they are not one of the major sources of lead emissions to the atmosphere, secondary lead smelters—i.e., factories and plants that recycle lead-bearing scrap and other lead-bearing materials to produce refined lead, lead alloys, or lead oxide—do themselves emit lead to the atmosphere. Emissions from these facilities—there were 51 in Canada in 1984—are of concern because they tend to be located in urban areas, as opposed to major industrial sources of lead, which are largely located in rural areas.

Lead is a poisonous substance and has no known physiological role in the human body. It interferes with a range of biochemical processes and has been shown to have adverse effects in many tissues and organ systems. Of these, the major targets are the central and peripheral nervous systems, the kidney, and the blood system. Absorption of ingested lead is usually the primary route of exposure. In the lungs, inhaled airborne lead, in the form of small particles, is efficiently transferred to the blood.

Recent exposure to lead is commonly determined by measuring blood lead levels, although the levels in bone, teeth, and other tissues, which are far more difficult to sample, may be more indicative of longer-term exposure. Children, especially very young children, are more sensitive to the effects of lead than adults; there is growing scientific evidence that blood lead levels in the 10–25 μg/dL range may be linked with various undesirable biochemical, neurobehavioural, and other subtle subclinical effects. Lead is readily passed to the fetus from the mother's blood, and thus there is some concern over exposure to lead in the womb. In adults, at similar blood lead levels, there is controversial evidence of possible effects on increased blood pressure.

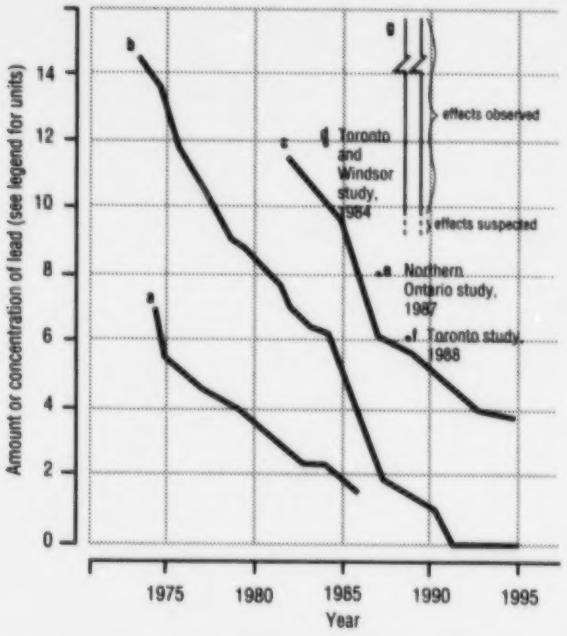
The atmosphere may not be the most significant route of exposure to lead, nor is lead from gasoline always the most important source. In some circumstances, a local source such as a smelter may dominate; in other situations, contaminated food, soil, dust, paint, or drinking water may be the major contributor to the total intake of lead. For young children, intake of lead in dust and soil via the "mouthing" of fingers and other objects is thought to be an important route.

Nevertheless, because essentially all Canadians are exposed to lead from gasoline use and because the dangers posed by lead are well established, the lead content of "unleaded"* gasoline was regulated in 1974. The lead content of "leaded" gasoline was regulated in 1976, and this regulation was tightened in 1987. Lead emissions from gasoline use will be effectively eliminated beyond 1990, because the addition of lead to gasoline will be prohibited after 1 December 1990. Very limited use in farming, commercial fishing, and trucking, where durability of engines is a concern, will be permitted, but the lead content of gasoline will be no more than 26 mg/L, less than one-tenth of today's regulated maximum level.

Regulation of the lead content of gasoline has meant that emissions to the atmosphere have declined by more than 86% between 1973, the year when lead emissions from gasoline use peaked at close to 15 000 t, and 1987 (Figure 22). Between 1974 and 1986, the average levels of lead in ambient air dropped by 78%. The highest maximum levels of lead in ambient air in Canada, about 1–2 μg/m^3, are in the central and western provinces, where motor vehicles are of an earlier model year on average than in eastern Canada. Table 5 shows Canadian air quality guidelines and standards for lead.

* Canadian regulations use the term "unleaded" gasoline. Another popular term is "no lead." The regulation applies to gasoline that has had no lead added to it during production. The lead level was not set at zero because of the possibility of contamination from equipment used to handle leaded gasoline during distribution and marketing.

Figure 22
Trends in lead levels in ambient air, trends in lead emissions, and blood lead levels



SOURCE: Based on information from Environment Canada; the Department of National Health and Welfare; Ontario Ministry of Health 1985, 1990; and Smith 1990.

a — Lead concentration in ambient air ($\mu g/m^3$ x 10).
b — Lead emissions from gasoline combustion (thousands of tonnes).
c — Lead emissions from all sources (thousands of tonnes).
d — Average blood lead levels in children in two southern Ontario urban areas (Toronto and Windsor) in 1984 (µg/dL).
e — Average blood lead levels in children in a northern Ontario urban area in 1987 (µg/dL).
f — Average blood lead levels in children in a southern Ontario urban area in 1988 (same Toronto neighbourhood as in the 1984 study) (µg/dL).
g — Current lowest range of blood lead levels at which deleterious effects have been observed in some population groups (µg/dL).

In a 1984 study of children living in two southern Ontario urban areas, Toronto and Windsor, the average blood lead level was about 12 µg/dL (Ontario Ministry of Health 1985). Lower average blood lead levels (about 8 µg/dL) were found in a 1987 study of children in urban areas of northern Ontario (Ontario Ministry of Health 1990). A 1988 study of children in the same Toronto neighbourhood used in the 1984 study indicated that the average blood lead level was about 6 µg/dL (Smith 1990). There is a significant association between air lead levels and blood lead levels. Traffic density is a determinant of air lead levels, and therefore lead emissions from gasoline use are the probable source of the blood lead. Deleterious effects have been observed in some population groups at blood lead levels as low as 10 µg/dL; however, some studies suggest that a threshold level for lead effects does not exist.

Table 5
Provincial air quality guidelines and standards for lead (in micrograms per cubic metre)

Province/Area	Exposure period		
	24 hours	Annual	Other
British Columbia	4,4,6[a]	3,4,4[a]	
Ontario			10[b]
			3[c]
Manitoba	5		
Quebec		0–2	
Newfoundland	5		2[d]
Montreal Urban Community			10[e]
			5[f]

SOURCE: Based on data provided by the Federal–Provincial Advisory Committee on Air Quality, Hazardous Air Pollutants Work Group.

[a] Equivalent to maximum desirable, maximum acceptable, and maximum tolerable levels.
[b] 0.5-hour point of impingement standard.
[c] Arithmetic mean for 30 days.
[d] Thirty-day exposure.
[e] One-hour exposure.
[f] Eight-hour exposure.

Class of chemicals

Volatile organic compounds

Volatile organic compounds (VOCs) is the term used to describe the organic gases and vapours that are present in the air. They are believed to be involved in ground-level ozone formation, and some VOCs are also toxic air pollutants. Emissions of VOCs are determined by subtracting emissions of methane, ethane, and chlorofluorocarbons—substances considered to be uninvolved in ground-level ozone formation and of low toxic potential—from total emissions of organic gases and vapours. On this basis, close to 1.8 million tonnes of VOCs are estimated to have been emitted in Canada in 1985. About one-half of this originated from the distribution, marketing, and use of gasoline.

Most emissions of VOCs are distributed largely in accordance with population distribution. Clearly identifiable single sources, emitting more than 100 t per year (e.g., petroleum refineries, petrochemical plants, plastics manufacturing), are responsible for only about 15% of the emissions. Sources more widely distributed and associated with population (e.g., fuel marketing, general solvent use, the application of surface coatings, dry cleaning operations, automobiles and trucks, fuelwood burning) account for about 85% of emissions (Federal–Provincial Long Range Transport of

Air Pollutants Steering Committee 1989). A clearer idea of the specific sources of VOCs in air should emerge from studies combining information on the kinds of VOCs and other compounds found together in ambient air, and their relative amounts, with meteorological information, such as wind direction.

Thousands of VOCs may be present in the air at one time. The concentrations found are generally in the low and sub-parts per billion range. Volatile organic compounds were measured in outdoor air in 13 urban areas in Canada in 1988. Approximately 100 compounds were found at that time. A recent analysis of the available data on VOCs in the United States indicates that 320 chemicals have been measured to date--261 in outdoor air and 66 in indoor air (Shah and Singh 1988).

The specific VOCs that have been identified in the air during some preliminary investigations by Environment Canada (1987) at sampling sites on Perth Avenue in the Junction Triangle area of Toronto and on Boulevard St-Jean Baptiste in Pointe-aux-Trembles, Montreal, have been classified as to whether they can promote ozone formation, whether they are a direct human health concern, or both. Many examples of both ozone-forming and toxic compounds were found. The sampling sites in Toronto and Montreal were selected because significant VOC emissions sources were known to be in close proximity to residential areas. Not all of the compounds suspected of being present in the air were measured because of limitations in the methodology, but enough were identified to give a good indication of the approximate concentrations and broad classes of compounds present.

Among the potentially toxic VOCs identified in the air are known human carcinogens. One of these, benzene, is of particular concern, because the primary emissions source—about 70% of all emissions—is fuel combustion in motor vehicles (Jaques 1988*b*). Benzene levels in the air of Canadian and US cities are of roughly the same magnitude (Dann 1987) (Table 6); however, there is no information available on the trends in benzene levels in the air of Canadian cities.

Because VOCs move readily through the air, more must be learned about their nature, their sources, and their collective capacity to cause harm, in order to guide future actions to protect Canadians.

Table 6
Comparison of benzene levels in air in Canada and the United States

Location	Average concentration (ppb)
Canada	
Sarnia	
— Centennial Park	6.0
Toronto	
— Junction Triangle	2.8
— 26 Breadalbane	0.9
— Queen's Park	3.4
Montreal	
— Pointe-aux-Trembles	5.7
— Pointe-aux-Trembles	3.6
— Pointe-aux-Trembles	3.0
Vancouver	
— Rocky Point Park	3.2
— Burnaby South	2.4
— Burnaby Mountain	4.6
Windsor	
— University Avenue	1.8
United States	
El Monte, CA	4.6
Riverside, CA	4.1
Boston, MA	1.1
Chicago, IL	1.3
Houston, TX	2.2
Las Vegas, NV	3.2
California[a]	3.3
United States[b]	3.8

SOURCE: Dann 1987.

[a] Statewide population-weighted annual mean, 1984.
[b] Estimated annual mean from five US metropolitan areas (1978–1982 data).

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs), sometimes referred to as polycyclic organic matter, consist of several hundred semivolatile organic hydrocarbons. Their properties and health effects in animals have been summarized in a recent publication (Withey 1986). Polycyclic aromatic hydrocarbons are ubiquitously distributed throughout the environment, having been detected in animal and plant tissues, sediments, soils, air, and surface water (Zedeck 1980; Santodonato *et al.* 1981).

Polycyclic aromatic hydrocarbons are produced when organic material is burned; the yield is particularly high when there is an insufficient supply of oxygen. Forest fires are probably the largest natural source of this kind of atmospheric pollution (Zedeck 1980), and claims have been made that residential wood combustion is the major source of urban pollution in North America (De Angelis *et al.* 1980). Motor vehicle emissions are also considered to be an important source of urban PAHs (Sawicki 1962). The combustion of natural or fossil fuel (wood, coal, or oil) for heat and energy and some industrial operations, such as coke ovens and aluminum smelting plants, represent significant point sources (Environment Canada 1988). Polycyclic aromatic hydrocarbons that are formed or dispersed in the vapour phase condense and are adsorbed onto the surface of respirable particulate matter, in particular tobacco smoke.

The most serious health effect associated with human exposure to PAHs is their ability to induce cancer in a variety of tissues. The International Agency for Research on Cancer (1973) identified, after reviewing the results of available animal studies and human epidemiological studies, some 27 individual compounds for which there is sufficient or limited evidence of their carcinogenicity. Indeed, Percival Pott, in 1775, was the first to identify incidences of industrial exposure to PAHs, in which young chimney sweeps exposed to soot developed scrotal cancer. Animal studies have shown that the noncarcinogenic effects of PAHs include growth retardation (Haddow *et al.* 1937), tissue necrosis (Philips *et al.* 1973), and severe irritancy, which can lead to skin and eye disorders (Hervin and Emmett 1976).

More than 100 PAHs have been identified in airborne particulate matter (Lee *et al.* 1977), and more than 300 have been isolated from tobacco smoke (Akin *et al.* 1976). The results of the analysis of PAHs in air, groundwater, finished drinking water, foods, and tobacco smoke are variously reported as "total PAHs," "carcinogenic PAHs," "benzo(a)pyrene," or as a series of identified individual members of this class (US Environmental Protection Agency 1980). Sampling and analysis methods have been quite variable, and the number of widespread, diverse sources of PAHs, coupled with seasonal variations, has made it difficult to produce accurate and complete inventories or to compare the data from different studies. A recent study conducted in the province of Quebec indicates that about 2500 t of PAHs are emitted annually, most of which is released to the air (Environment Canada 1988).

In several studies conducted across Canada (Atwell *et al.* 1984; Dann 1988), a number of PAHs that are known human carcinogens were detected. Levels of benzo(a)pyrene between 9.0 and 15 ng/m^3 were found near point sources, such as residential wood burning, coke ovens, and an aluminum smelter. Air in urban centres contained benzo(a)pyrene at levels below 1.0 ng/m^3, and this indicates a significant decrease since the 1950s and 1960s. A remote site (Walpole Island, Ontario) had a level of 0.06 ng/m^3, presumably as a consequence of long-range transport (Table 7).

Guidelines and standards for PAHs have been set in the United States (by the Occupational Safety and Health Administration) for coke oven emissions and coal-tar pitch volatiles. These standards are based on a sampling and analysis procedure that analyzes the benzene-soluble PAH fraction (US Environmental Protection Agency 1980). The World Health Organization (1970) has also set standards for drinking water, based on the composite analysis of six PAHs. Recent estimates of health risk for PAHs have been based on benzo(a)pyrene content or its equivalent in PAH mixtures (World Health Organization 1987).

Table 7
Average benzo(a)pyrene levels at sampling sites in Canada

Location	Mean benzo(a)-pyrene level (ng/m^3)	Year	Probable major source
Kitimat, BC	14.1	1984	Aluminum smelter
Whitehorse, Yukon	8.9	1982–1983	Residential wood burning
Sydney, NS	1.3	1981–1982	Coke ovens
Montreal, Que.	0.6	1984–1986	Automobiles
Windsor, Ont.	0.61	1987–1988	Automobiles
Toronto, Ont.	0.3	1984–1986	Automobiles
Walpole Island, Ont.	0.06	1988	Long-range transport

Source: Dann 1988; Environment Canada 1989.

Activity—Residential wood combustion

Canadians burned an estimated seven million cubic metres of wood in 1986 to heat their homes. Canada ranks high among wood users on a per capita basis. Today, to offset rising energy costs and because of public demand for aesthetic reasons, most new homes in urban areas come equipped with at least one fireplace. Heating with wood has always been popular in rural areas, as well.

Unfortunately, in some parts of the country, wood burning is leading to some serious air pollution problems (Roche Envirobec 1983; Bethell Management Ltd. 1986), especially on days when meteorological conditions fail to disperse the woodsmoke. Woodsmoke contains a large amount of particulate matter, carbon monoxide, oxides of nitrogen, creosote, and PAHs. Incomplete combustion of wood produces highly visible woodsmoke, and poor wood-burning practices, such as the use of "green" wood, and inefficient fireplaces, stoves, and furnaces increase the amount of woodsmoke produced.

The Riverdale residential subdivision of Whitehorse, Yukon Territory, has experienced deteriorating air quality from excessive woodsmoke in recent years. Figure 23 shows the average level of suspended particulates in Riverdale each day during January and February 1988 (Pulleyblank and Wile 1988). As there were 17 days when the levels exceeded the 24-hour maximum acceptable level national air quality objective of 120 µg/m^3 and three days when the 24-hour maximum tolerable level objective of 400 µg/m^3 was exceeded, irritant effects of particulate on the lung are the principal concerns over the short term. The objectives, however, are not suitable for evaluating potential long-term toxic effects due to substances absorbed on the woodsmoke particles.

The Riverdale air quality problem

An extensive study of deteriorating air quality from excessive woodsmoke has been conducted in the Riverdale residential subdivision of Whitehorse, Yukon Territory. The city of Whitehorse is located in the south central Yukon 150 km from the Gulf of Alaska, at an elevation of 670 m. The climate is continental subarctic; however, because of its close proximity to the ocean, Whitehorse is frequently near the boundary between arctic continental and maritime continental air masses. During periods when a cold air mass is established over the region, ground-based temperature inversions often occur, resulting in air stagnation (Pulleyblank and Wile 1988).

Riverdale, located just south of Whitehorse, has approximately 1350 homes, of which 700 are primarily heated with wood during the winter months. Riverdale is surrounded on three sides by steep forested slopes and on the fourth by the Yukon River. In 1979, a forest fire north of the city resulted in a plentiful supply of fire-killed wood. As a result of the topographic conditions, stable winter air masses, and the popularity of wood heating, thick, foglike woodsmoke pollution events became increasingly common during the 1980s (Pulleyblank and Wile 1988).

Air pollution at Riverdale has been studied since 1981. The pollutants have been characterized as being mainly fine particulate matter with PAHs bonded to it. Monitoring shows that the levels of particulate matter are highest in the period from December to February but extremely variable from day to day. National air quality objectives for particulate matter are frequently exceeded during the heating season.

Early attempts to predict when episodes of high pollution would occur were not successful because of insufficient meteorological data. Efforts to solve the problem through voluntary "no-burn" periods did not produce the desired results. Since 1986, however, the city, territorial, and federal governments have taken steps to resolve the problems at Riverdale:

- The proper operation of woodstoves was demonstrated to the public through a series of workshops.
- Specifications for the correct installation of woodstoves are being developed.
- In-home performance studies of new woodstove technologies are being conducted.
- Continuous particulate monitoring during burning periods and meteorological monitoring have been in effect since the end of 1987.
- A city bylaw was passed on 8 December 1986 providing the authority to declare "no-burn" periods and to control open burning and the opacity of woodstove emissions.
- A better air quality prediction capability has been developed.
- A 24-hour-per-day woodsmoke information "hot-line" gives current and predicted particulate levels, and "no-burn" periods are announced through the media and on the hot-line. Procedures to follow during "no-burn" situations are in place.

During the 1987–1988 wood-burning season, the residents of Riverdale worked cooperatively with the city bylaw inspector to improve wood-burning practices, with the result that no "no-burn" periods were declared during that period. Greater public awareness and education are seen as essential to the resolution of the problem.

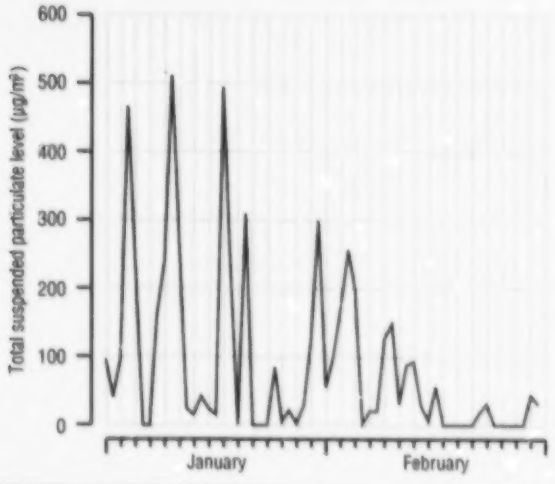
Wood burning is also popular in other parts of the country. In Atlantic Canada, air quality monitoring in response to complaints from the public shows that total suspended particulate concentrations there were consistently lower than in Riverdale (Kozak 1985) (Table 8). There were, however, days during this study when residential wood combustion is believed to have contributed as much as 80 $\mu g/m^3$ to the total suspended particulate loading.

Geographical area

Junction Triangle

Junction Triangle is an industrial and residential area in northwest Toronto. About 6000 residents and 24 industries, many of which have operated for more than 25 years, occupy the 0.68-km^2 area. Over the past two decades, residents have complained to city authorities about the potential health effects of noxious odours that they claim come from

Figure 23
Total suspended particulate matter levels in Whitehorse (Riverdale) during January and February 1988



SOURCE: Pulleyblank and Wile 1988.

these industries. They questioned the compatibility of this mix of land use and feared most for the health of their children. Preliminary epidemiological studies between 1982 and 1984 revealed sufficient evidence that the children of Junction Triangle experienced symptoms of ill health frequently enough to warrant recommending a more in-depth study. The perception of the problem among adults was found to be high (Spitzer 1984).

Between April and May 1985, screening tests designed to detect the kinds of symptoms of ill health associated with industrial pollution—skin rashes, allergies, eye and throat irritation—were carried out on 1226 children living in or attending school in Junction Triangle. This screening led to the more detailed assessment of 421 children. A control group of comparable children living elsewhere was also screened and assessed. The study did not demonstrate any serious differences between the two groups of children but acknowledged that there may have been differences that the study did not reveal (City of Toronto 1985). In 1986, the City of Toronto Public Health Department and the Ontario Cancer Treatment and Research Foundation conducted a study of the incidence of cancer in Junction Triangle and concluded that there was no evidence of increased cancer incidence.

Table 8
Total suspended particulate (TSP)[a] levels measured in Atlantic Canada during the wood-burning season

Period	Location	Average TSP level[b] (μg/m³)	Maximum TSP level (μg/m³)
February – April 1984	Truro, NS	~13–20	~40
February – April 1984	Lower Sackville, NS	~15–20	~40
December 1984 – March 1985	Lower Sackville, NS	~10–40	~123
8 January – 21 February 1985	Fredericton, NB	~31–34	~55

SOURCE: Kozak 1985.

[a] About one-half to three-quarters of the particulate matter is thought to be fine particulate matter and thus to have originated from residential wood combustion.
[b] Average TSP levels are expressed as a range because more than one TSP monitor was used at each location.

Southwest Ontario

Late in 1986, the Greater Detroit Resource Recovery Authority announced that a municipal waste incinerator capable of burning 4000 tons of waste per day would be constructed in downtown Detroit, 6 km from the Canada–US border. There was concern that the best available control technology was not going to be used. The potential impact of emissions from this incinerator on the air quality in Windsor led to the establishment of a monitoring program for toxic substances associated with incineration. Environment Canada, in cooperation with the Ontario Ministry of the Environment and the Walpole Island Indian Band, set up two monitoring sites in southwest Ontario, one located in downtown Windsor (operation commenced in July 1987) and the other located on Walpole Island in Lake St. Clair (operation commenced in January 1988). The monitoring was designed to gather background data prior to the startup of the incinerator.

Among the ambient air pollutants measured are dioxins, furans, PCBs, chlorobenzenes, chlorophenols, PAHs, VOCs, inhalable particulate matter, and several metals.

For the Windsor monitoring site, data for the period July 1987 to September 1988 have been evaluated; for the Walpole Island monitoring site, data for the period January 1988 to September 1988 have been evaluated. Dioxins and furans were detected at the Windsor site but at levels well below Ontario's provisional ambient air quality guideline of 30 pg/m³. At the Walpole Island site, detectable levels of

dioxin were found, but levels were approximately three times lower at the Walpole Island site than at Windsor. Levels of PAHs detected in Windsor were found to be comparable with those in other North American urban centres. Polychlorinated biphenyls were found at very low levels in Windsor, significantly lower than Ontario's annual ambient air quality guideline of 35 ng/m^3. At the Walpole Island site, PCB levels were below detection limits for all but two samples. Concentrations of inhalable particulate matter and sulphate were found to be high at both sites on some summer sampling days, but these concentrations were not in excess of the provincial ambient air quality standards (Environment Canada 1989).

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Chapter 5

Important regional and global air pollution issues

Introduction

There are several air pollution concerns facing Canada today. Some of these—e.g., the degradation of air quality in urban centres from the accumulation of gases, particulate matter, and vapours in large cities and heavily populated areas, and the contamination of food, water, soil, and air by organic and inorganic chemicals released into the atmosphere from automobiles, heavy industries, factories, agricultural activities, and waste incineration—have been discussed earlier in this report (see Chapters 3 and 4).

In this chapter, emphasis is placed on two important regional issues—acid rain and pollutants in the Arctic atmosphere—and three global issues—stratospheric ozone depletion, climate change, and atmospheric radioactivity.

Regional issues

Acid rain

Life on Earth is totally dependent on the continuous interaction and transformation of the chemical substances that comprise the planet. Through chemical reactions, nutrients are derived from food, and energy is stored and released. The amounts and the physical and chemical properties of the substances in the environment are of fundamental importance in maintaining the quality of ecosystems. There are limits, however, to the chemical conditions that can be tolerated without biological damage, and, not surprisingly, pollution can cause those limits to be exceeded. Acid rain is one pollution problem that vividly demonstrates what happens when these limits are exceeded.

Acid rain is any form of precipitation (e.g., rain, snow, hail) that has been acidified by atmospheric pollutants. The three main sources of the pollutants responsible for acid rain are industrial emissions, power plants, and automobiles. Sulphur dioxide, formed principally from burning sulphur-containing coal and processing sulphur-containing ore, remains airborne for several days, during which time it reacts with water to form sulphuric acid. Likewise, oxides of nitrogen, mainly from fuel combustion, form nitric acid in the air. When precipitation washes these acids out of the air and returns them to Earth's surface (a process called wet deposition), there is evidence that virtually anything the acids contact, such as soil, water, plants, and structural materials, can be affected to some degree. Even in the absence of precipitation, direct contact with acid aerosols can occur, a process referred to as dry deposition. There is now evidence to show that the finely dispersed droplets of water in fog also contain acids.

Acid rain became an international issue in the 1960s. Taller smoke stacks were introduced as one solution to local air pollution problems. The thinking was that by releasing the pollutants at higher altitudes, they would be diluted by air and not reach harmful concentrations at ground level. The philosophy of using tall stacks was soon proven to be flawed. Local air quality was improved in this way as predicted, but the stacks allowed more pollutants to be put in the air than was possible with shorter stacks. There is also evidence to demonstrate that the plumes, or bands of smoke, from tall stacks sometimes travel hundreds of kilometres. Even after the visible plume has dispersed, the pollutants themselves move even longer distances, at times thousands of kilometres from their source. When the pollutants eventually come back down to Earth through wet or dry deposition, they may have crossed international boundaries and been transformed chemically into more harmful substances. The most significant property of the acids formed from pollutants is that they are strong mineral acids.

In the absence of pollution, most of the acids found in precipitation, soil, and water are weak acids. The most common weak acid is carbonic acid, which is formed when carbon dioxide, naturally found in the atmosphere, dissolves in rain water. Carbonic acid is also formed in soil and surface water. Organic acids, another type of weak acid, are formed in soil and water when organic matter, such as leaves, decomposes. Most soils and surface waters therefore contain both carbonic acid and some organic acids. Why then, with all of this weak acid being produced year after year, does the acidity not build up to dangerously high levels, even without pollution? The answer lies in the reactions that take place between weak acids and other substances in the environment.

Figure 24 is a conceptual model of the "bicarbonate" buffering system in soil and water, the natural set of chemi-

Important air pollution concerns for Canadians

- Degradation of air quality in urban centres
  - — highly visible forms of air pollution often associated with large cities and heavily populated areas
  - — gases, particulates, and vapours are emitted and accumulate in air over several days
  - — some pollutants highly reactive in presence of sunlight and produce "secondary" air pollutants (e.g., ozone), which may be more harmful to human health and the environment than the original pollutants.

- Toxic air pollutants
  - — potentially dangerous chemicals released into the atmosphere from automobiles, heavy industries, factories, small enterprises, agricultural activities, waste incineration, and use of chemicals in homes
  - — chemicals contaminate food, water, soil, and air, and may damage health and threaten environment

- Acid rain
  - — caused by sulphur dioxide from smelters in Canada and coal-burning power plants in Canada and the United States and nitrogen oxides, which arise whenever fuel is burned
  - — these gases form strong acids in the atmosphere and can be transported over long distances
  - — acids acidify lakes, rivers, and soils, which adversely affects aquatic life, forests, and vegetation
  - — human health effects are suspected

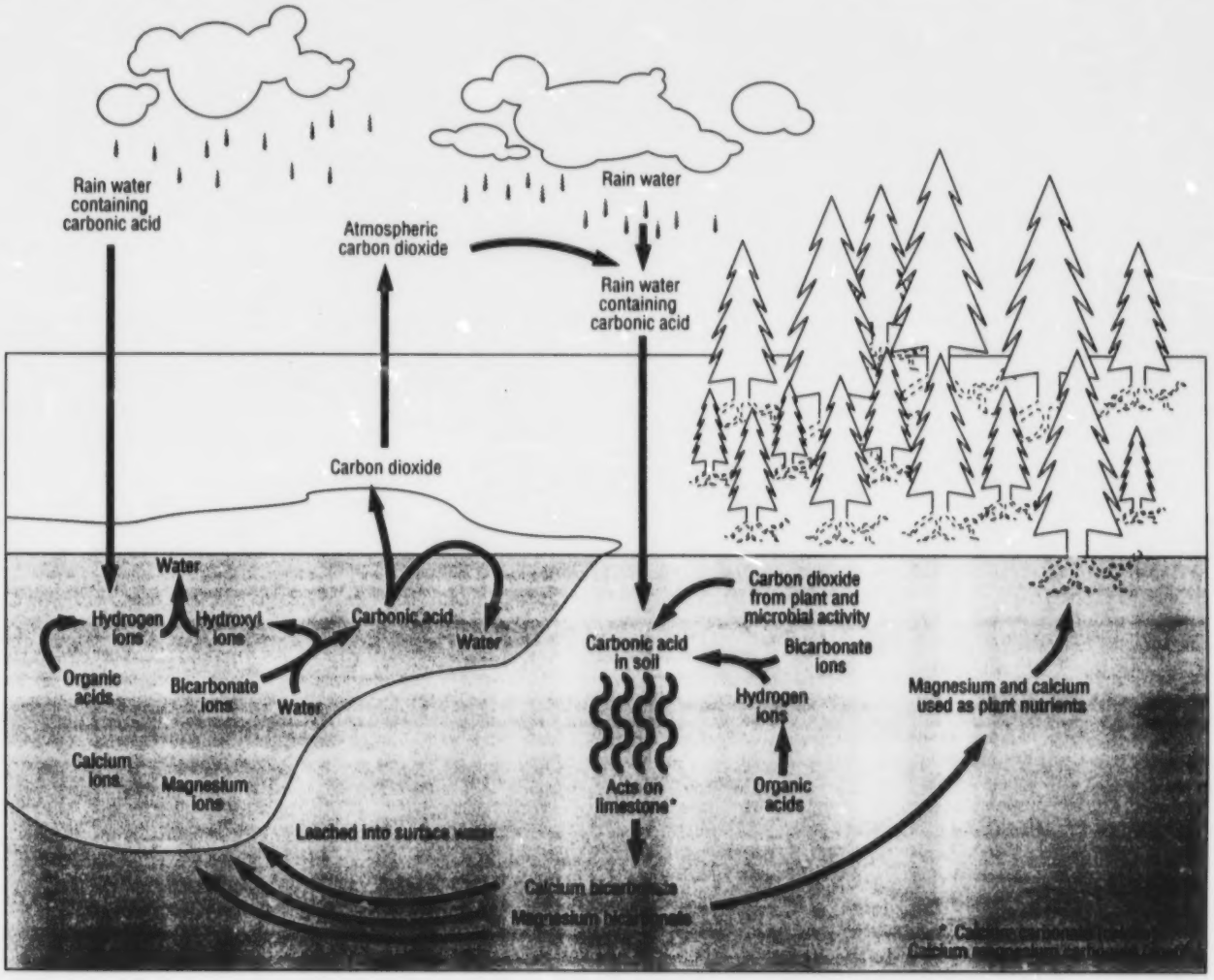
- Pollutants in the Arctic atmosphere
  - — layers of haze reported in the Arctic air mass between December and April each year contain pollutants that have been transported into the Arctic from other parts of the northern hemisphere
  - — when pollutants are deposited on snow and ice, natural foodstocks of Arctic inhabitants may be contaminated, and ecosystem may be placed under additional stress

- Stratospheric ozone depletion
  - — stratospheric ozone absorbs most of the most damaging portions of the sun's ultraviolet radiation before it can reach Earth's surface
  - — man-made chemicals, e.g., chlorofluorocarbons and halons, react with and deplete ozone in the stratosphere, causing increased levels of ultraviolet radiation to reach Earth

- Climate change—global warming
  - — Earth warmed by incoming solar radiation and cooled by loss of heat through thermal radiation
  - — atmospheric gases impede loss of thermal radiation, establishing an equilibrium and thus climate at Earth's surface as we know it
  - — amounts of carbon dioxide and other gases capable of impeding thermal radiation loss have been increasing steadily, and excessive global warming resulting in climate change (the greenhouse effect) is predicted if trend continues

- Atmospheric radioactivity
  - — radiation from a variety of sources, including natural ones, has the potential to cause health effects by inducing changes in living organisms at the cellular level
  - — exposure to low background doses of radiation is a natural occurrence
  - — public attention focuses on the possibility of nuclear reactor accidents, which could result in exposure to high doses of radiation for short periods
  - — one naturally occurring radionuclide, radon, is of concern as an indoor air pollutant (Note: indoor air pollution is not the focus of this report, but it is an important consideration when evaluating total human exposure to air pollutants)

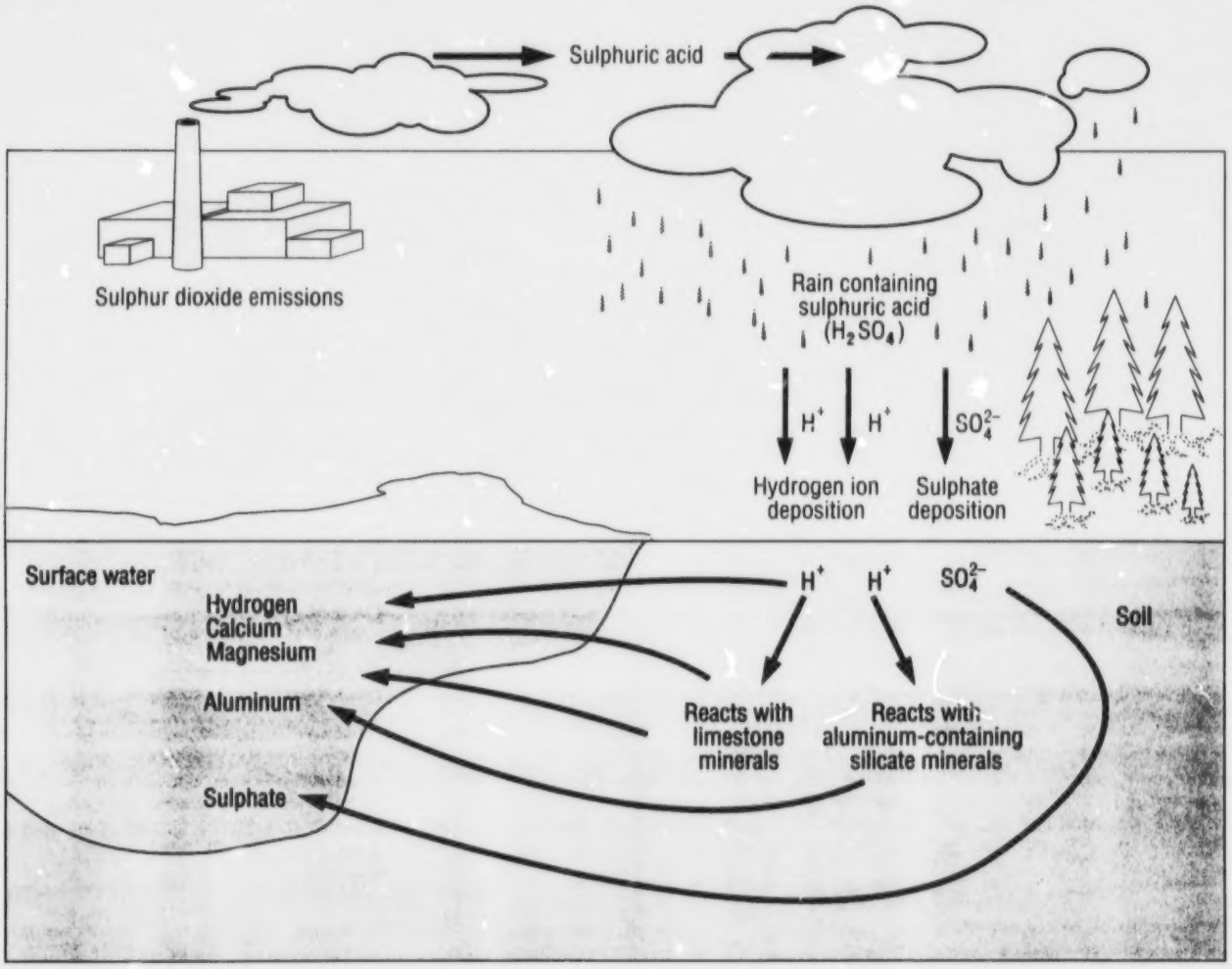
Figure 24
Conceptual model of the bicarbonate buffering system in soil and surface water



SOURCE: Based on information in Wetzel 1975.

cal reactions that prevent acidification. As Figure 24 depicts, carbonic acid, whether formed in the soil or water or deposited in precipitation, does not acidify surface water, for two reasons. First, in soil, carbonic acid reacts with limestone and other minerals, forming bicarbonate ions and effectively neutralizing the acid. This is the natural soil weathering process and is an essential source of nutrients for plant life (i.e., the physical and chemical decomposition of soil minerals). Secondly, carbonic acid may decompose to release carbon dioxide back into the atmosphere. It is important to note that most of the calcium and magnesium ions from soil weathering also find their way into surface water. The concentrations of these ions are measured by scientists to indicate the quality of surface water. Plants use some of the calcium, magnesium, and other ions as nutrients. Limestone also buffers organic acids in soil, as indicated in Figure 24. As long as the "weathering" process keeps pace with the influx of acids, the acidity of the soil and water will remain fairly constant within biologically acceptable limits.

Figure 25
Conceptual model of mineral acid deposition and the transport of calcium, magnesium, aluminum, sulphate, and hydrogen ions from soil to surface water



The story is quite different, however, when the soil receives strong mineral acids in addition to natural weak organic acids (Figure 25). The mineral acids introduce a new set of chemical reactions into ecosystems, which overwhelm the weathering process and result in the dissolution of metals, such as aluminum. If there is not enough limestone or other reactive soil material to neutralize the large influx of hydrogen ions (which are responsible for acidity) from the strong acids, the concentration of hydrogen ions in soil increases. That in itself can be harmful, because some of those hydrogen ions will leach out of the soil into surface water and acidify the water. If the strong acid is sulphuric acid, sulphate ions will also be added in large amounts to the soil. Sulphate ions tend not to bind with soil particles in the geologically immature soils characteristic of Canada and are not used in large amounts as nutrients by plants, so they remain dissolved in the water in the soil. As water percolates through the soil, both hydrogen ions and sulphate ions enter surface water or groundwater. The movement of sulphate ions causes calcium, magnesium, and other trace metals to leach from the soil, depriving plants of these nutrients. At higher levels of soil acidity, aluminum, a common soil constituent, is also carried to surface water and groundwater. This aluminum is highly toxic to fish because it affects gill function.

Changes in lake water chemistry caused by acid rain

Some recent findings illustrate the current level of understanding of the acid rain problem and provide strong evidence that acidification of lakes is principally a result of the deposition of sulphuric acid to the soils in the watershed. A healthy lake maintains a fairly stable pH* because it is buffered by the calcium–magnesium bicarbonate system produced by the normal carbonic acid weathering reactions. A healthy lake therefore should contain equivalent amounts of calcium plus magnesium and alkalinity (a measure of a lake's capacity to neutralize acidic compounds)—i.e., the ratio of alkalinity to calcium plus magnesium should be 1:1. Figure 27 illustrates where some Canadian lakes fall on a graph relative to a line representing the 1:1 ratio. Lakes in the Muskoka–Haliburton region of Ontario fall below the line, indicating that there is a deficiency of alkalinity in the water. This is consistent with the theory that acid rain results in a loss of alkalinity and in the leaching of calcium and magnesium out of soil into surface water. The ratios are even lower for lakes in the Sudbury area.

To further substantiate the claim that acid rain has caused the changes in the lake water chemistry, calcium plus magnesium has been compared with the sulphate and alkalinity content of lake water (Figure 28) for the same lakes depicted in Figure 27. For all of the lakes examined, excess calcium plus magnesium is equivalent to sulphate, indicating that the sulphate is responsible for the observed changes in water chemistry.

Figure 29 shows the status of surface waters in eastern Canada as determined from the ratio of alkalinity to calcium plus magnesium, based on water samples taken from about 8000 different lakes over a number of years (Jeffries 1986). There are many areas where the ratio has been reduced because acidification has decreased the alkalinity, increased the levels of calcium plus magnesium, or both. When the ratio becomes zero (0.0 on Figure 29), the lake is considered to be "acidic." Acidic lakes are devoid of fish and have suffered the maximum biological damage. It has been estimated that 14 000 lakes are acidic in eastern Canada, and some rivers in Nova Scotia have been severely affected. Large areas of Ontario, Quebec, and Nova Scotia fall within the 0.2 (ratio) contour, meaning that the surface waters have less than 20% of the alkalinity that they should have from normal weathering processes.

Figure 30 helps understand the cause of the low ratios in Figure 29 (Jeffries 1986). The contours for the ratios of sulphate to calcium plus magnesium in Figure 30 mirror the contours in Figure 29, with large ratios in Figure 30 corresponding to low ratios in Figure 29. This means that where alkalinity has declined, sulphate levels have risen, and this has occurred where sulphate deposition is greatest (Figure 31).

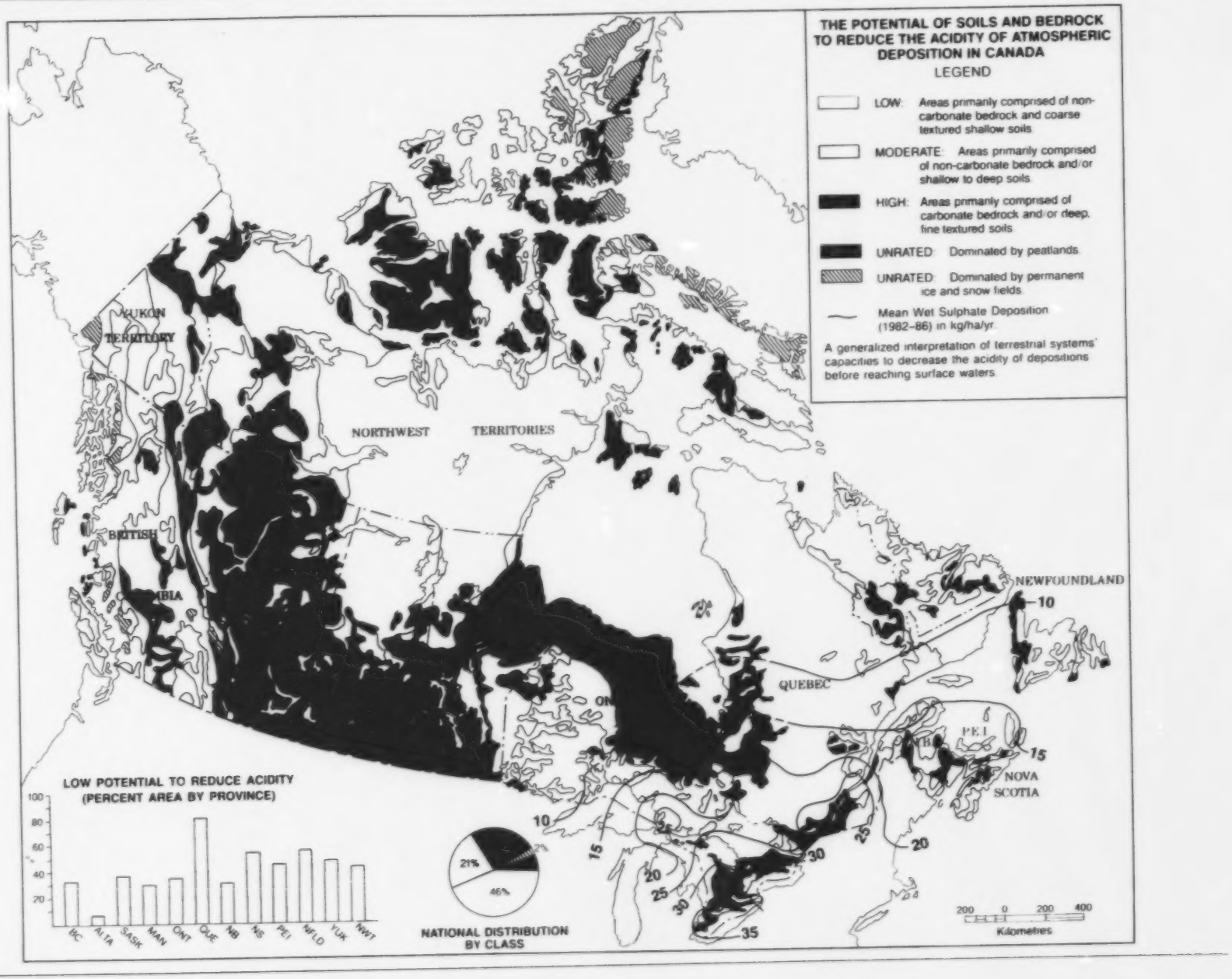
* pH unit is the scientific unit used to describe the strength of acids and bases, and pH values range from 0 to 14. A pH value of 7 means that a solution is neutral—i.e., neither acidic nor alkaline. Values below 7 represent acidic solutions: the lower the value, the more acidic the solution. The pH scale is logarithmic, so a change of one pH unit represents a 10-fold change in hydrogen ion concentration, or acidity. Thus, an acid of pH 5 is 10 times stronger than an acid of pH 6, and an acid of pH 4 is 10 times stronger than an acid of pH 5, and so on. Pure water—in equilibrium with atmospheric carbon dioxide—has an acidity of about 5.6. Natural rainfall, however, can have pH values as low as 5.0, because it always contains small quantities of natural strong acids.

If the strong acid is nitric acid, however, there is not the same concern. Nitrate ions are used as nutrients by plants, a fact substantiated by the observation that, despite nitrate deposition, very little nitrate is found in acidified surface water in Canada. The acidifying effect of nitrate is minimal. Over the long term it is the sulphate component of acid rain that acidifies surface water (Brydges 1986).

Scientists study acid deposition by focusing on specific bodies of water, on watersheds, and on the precipitation that feeds them. Stream water and precipitation are sampled and analyzed in detail to determine the concentrations of such ions as calcium, magnesium, sulphate, aluminum, and hydrogen. The stream flows and the amount of precipitation are measured. Knowing these facts, scientists can calculate the amount of material entering a watershed and moving through it. They can then begin to understand what is happening and what substances are responsible for observed changes in the environment.

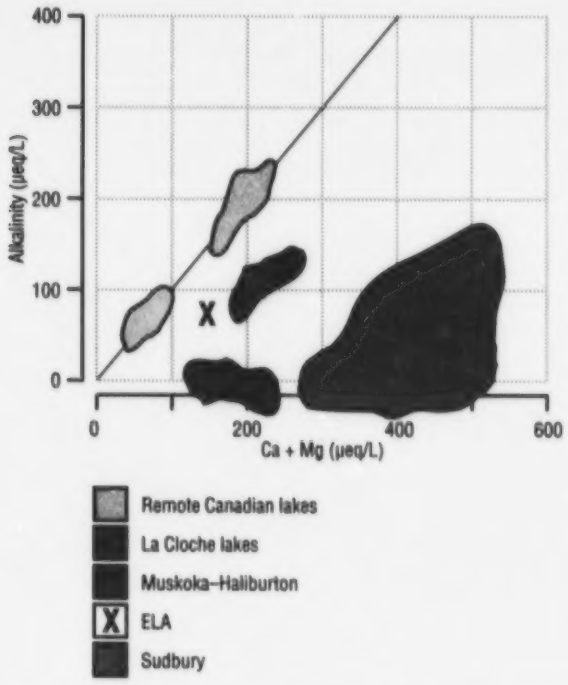
Although often perceived as being a problem only in eastern Canada, acid rain occurs throughout the country. Rain and other forms of precipitation enter aquatic ecosystems mainly through surface runoff and groundwater flow. The amount deposited directly into aquatic ecosystems is relatively small. Based on a study of the different types of soil and bedrock found across Canada, 40% of the land area is considered to have a low potential to neutralize acid rain. The aquatic ecosystems in this area (Figure 26) are therefore highly sensitive to acid rain. Only 23% of Canada's aquatic

Figure 26
The potential of soils and bedrock to reduce the acidity of atmospheric deposition in Canada



SOURCE: Environment Canada 1988a.

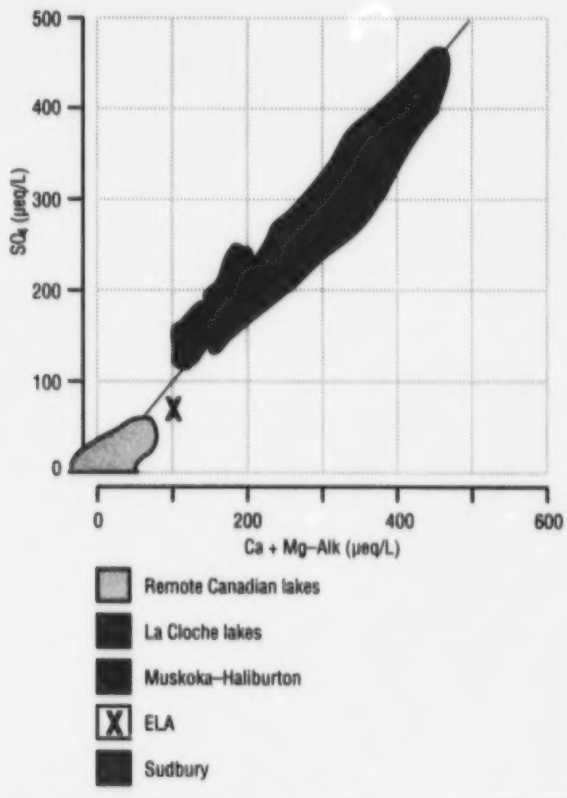
Figure 27
Ratios of alkalinity to calcium plus magnesium for some Canadian lakes



SOURCE: Dillon *et al.* 1980.

NOTE: The shaded areas represent the distribution of the data for the lakes in each region indicated in the legend.

Figure 28
Ratios of sulphate to excess calcium plus magnesium for some Canadian lakes



SOURCE: Dillon *et al.* 1980.

NOTE: The shaded areas represent the distribution of the data for the lakes in each region indicated in the legend.

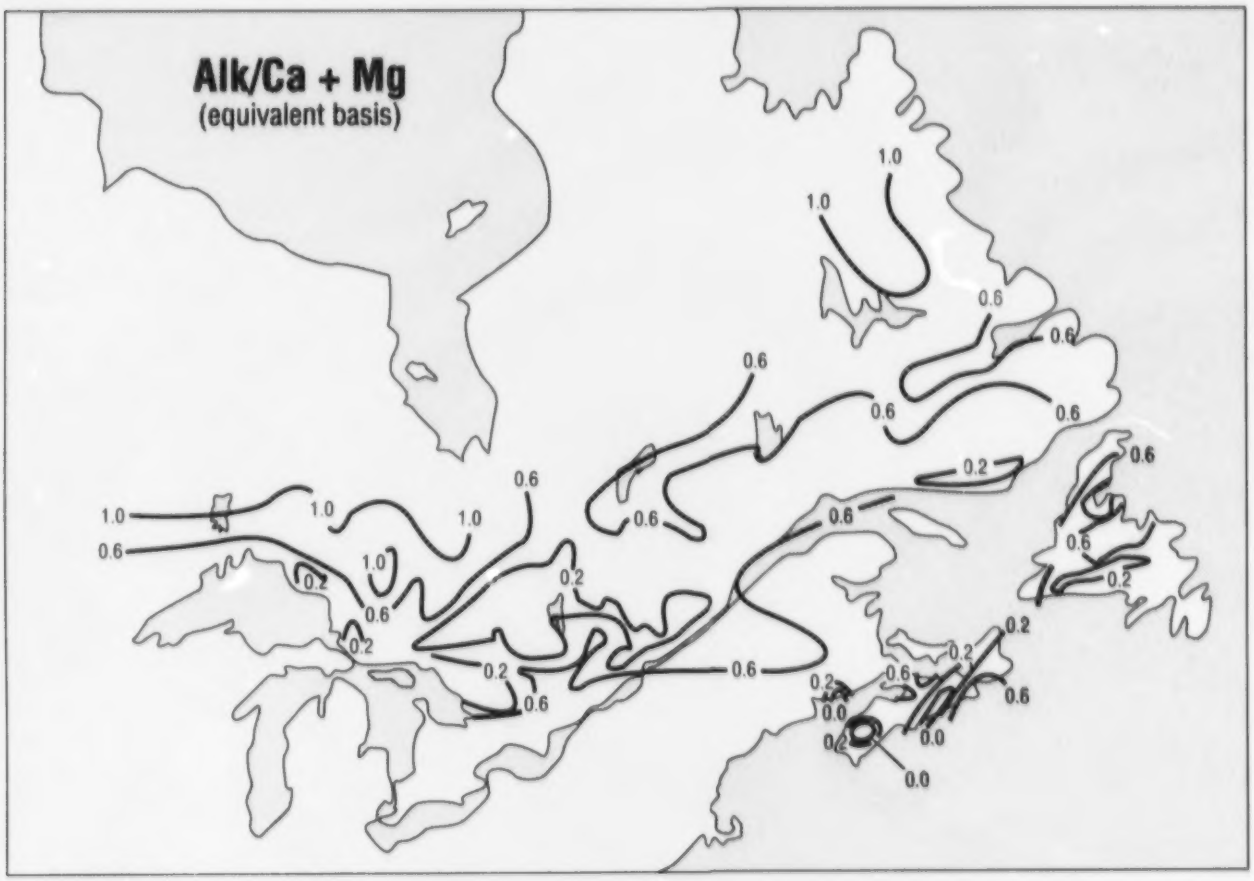
ecosystems are located in land areas with a high potential to neutralize the acidity of precipitation naturally (Environment Canada 1988*a*).

There are many biological indicators of the acidification of surface water. Growth of filamentous algae is one sign that the biological nature of a lake is changing under acid stress. Loss of fish populations has also been documented. Individual species of algae and zooplankton may be lost with little obvious immediate effect. Eventually, however, the entire aquatic ecosystem collapses, because too many key components have been lost. The changes do not happen instantaneously but over long periods.

Experimental acidification of a small Precambrian Shield lake with low acid-neutralizing potential—Lake 223 in the Experimental Lakes Area of northwestern Ontario—has provided important information on the effects of acidification on whole ecosystems (Schindler *et al.* 1985). Results suggest that early ecological damage may be more extensive than was previously believed. For example, stress on aquatic ecosystems was observed at a pH as high as 5.8, and some species were lost.

Figure 32 depicts another concern associated with surface water acidification—the decline in fish catch, in this example from a number of Nova Scotia salmon rivers. The dotted line represents the trend in the salmon catch in rivers that currently have a high acidity. The solid line represents the trend in the catch in rivers that currently have a low acidity. In the 1940s and 1950s, the fish catch began to decline in some rivers. The belief now is that the decline was a response to acidification; unfortunately, the decline started well before any chemical studies of these rivers were con-

Figure 29
The status of surface waters in eastern Canada as measured by the ratio of alkalinity to calcium plus magnesium



SOURCE: Jeffries 1986.

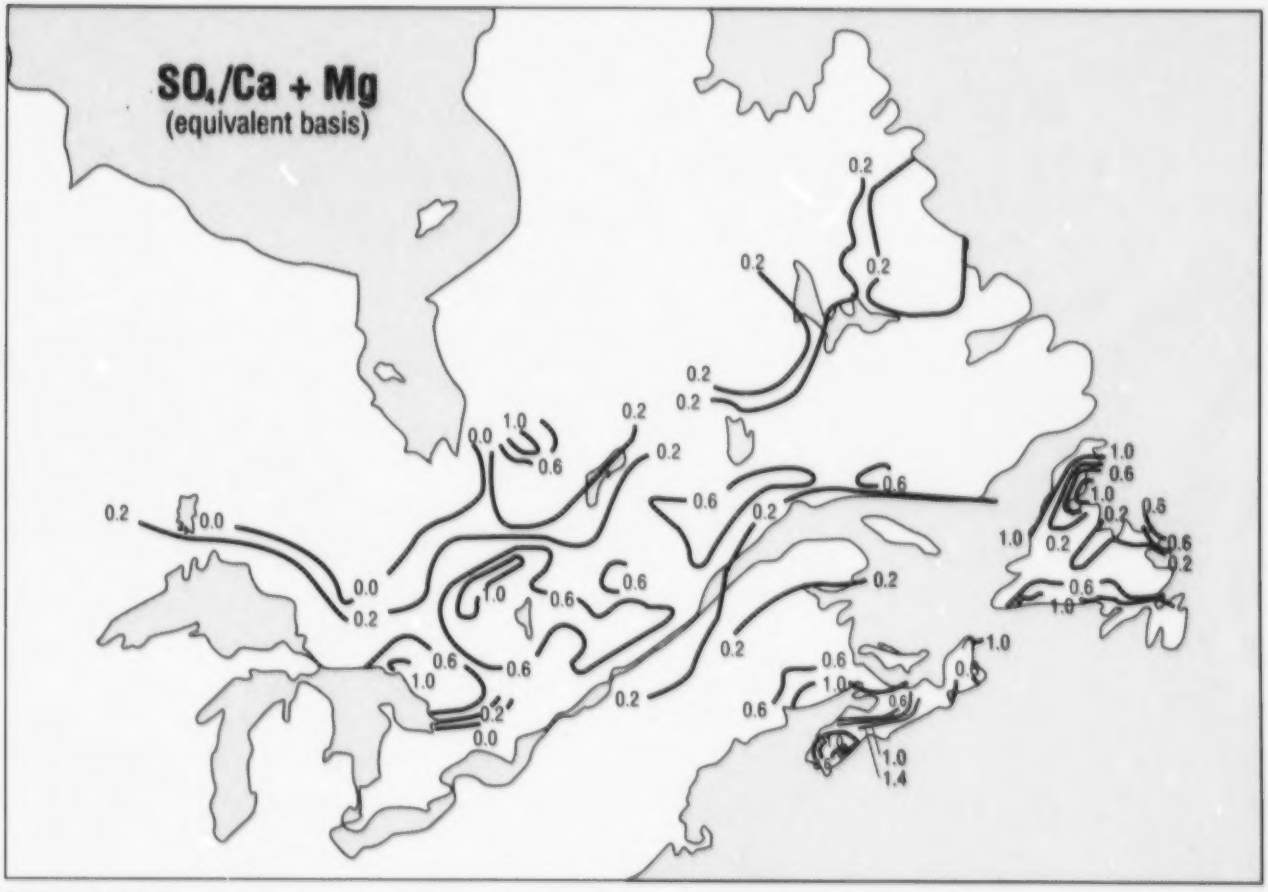
NOTE: This map is based on approximately 6000 sample points.

ducted. This example illustrates a common problem faced when investigating long-term biological change. Historical information on acidification is often lacking. Even a water chemistry record as short as 10 years is regarded as lengthy, and there are only a few examples of 20-year records. Long-term projections in the future are difficult to make on the basis of such short historical records.

Although the effects of acidification on soils, surface water, and aquatic ecosystems are quite well documented, there is a lot less certainty about the effects on forest ecosystems. Until about 1980, when damage was first noticed in German forests, there was little concern for forests. Since then, damage to forests in other parts of Europe and in North America has been observed. Attention has also been focused on the obvious decline of sugar maple in parts of eastern Canada. Studies to date suggest that the damage is due to a complex set of factors, such as drought, climate, air pollutants, and acidification, acting in concert. Acidification is known to change soil chemistry, which has direct effects on forest vegetation.

Limestone, marble, and sandstone building materials are also vulnerable to damage by sulphur dioxide and sulphuric acid, which react with the calcium carbonate in these materials, forming calcium sulphate. The calcium sulphate that is formed has a larger volume than the calcium carbonate, with the result that the surfaces of the structures expand

Figure 30
The status of surface waters in eastern Canada as measured by the ratio of sulphate to calcium plus magnesium



SOURCE: Jeffries 1986.

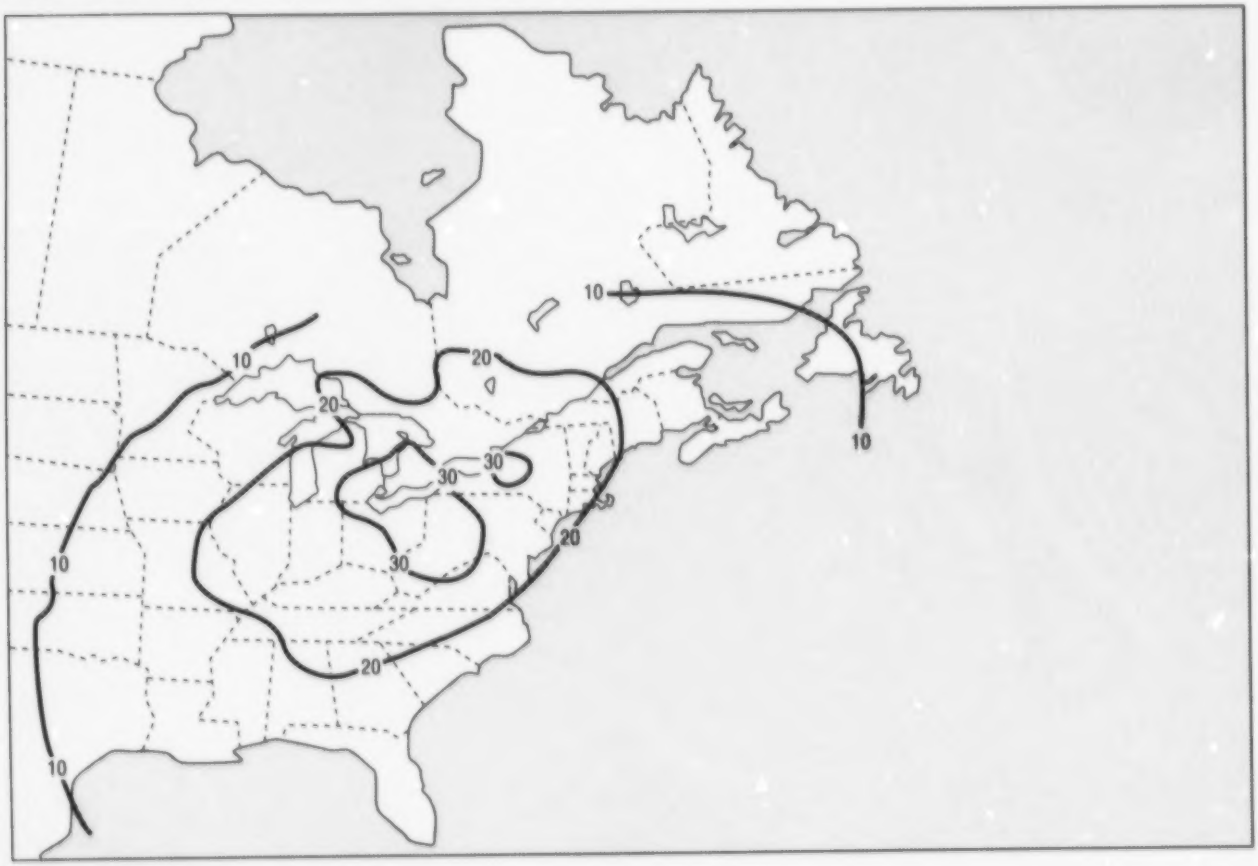
and begin to crack and crumble. The extent of the damage to buildings is hard to determine, because without pollution they can have an expected life span of perhaps 500 years. A five- to six-year study, however, may not be able to quantify an accelerated rate of damage. Indications are that the life span of buildings will be reduced by pollution damage.

As a result of local air quality problems in urban areas and near large smelting operations, Canada has been implementing sulphur dioxide controls for many years, notably in Trail, BC, in the 1930s and in the Sudbury area starting in the 1960s. These control actions were driven by the need to improve local air quality, and, during the 1970s, total emissions of sulphur dioxide in eastern Canada were reduced by 30% (Figure 33). Similar actions have been taken in other countries. For example, in the United States, there was a decrease of about 25% in sulphur dioxide emissions over the same period.

During the 1970s, however, as the understanding of long-range transport of pollutants improved, it was obvious that other control actions would be necessary (Brydges 1988). In 1981, Canada introduced national emissions guidelines for oxides of nitrogen, sulphur dioxide, and particulate matter from new thermal-powered plants. In 1982, both Inco Ltd. at Sudbury and Ontario Hydro were required to reduce emissions in response to the need to protect against long-range transport of air pollutants.

During 1984 and 1985, the seven eastern provinces and the Canadian federal government reached agreement on

Figure 31
Mean annual sulphate deposition pattern (kg/ha per year) in North America, 1982–1987



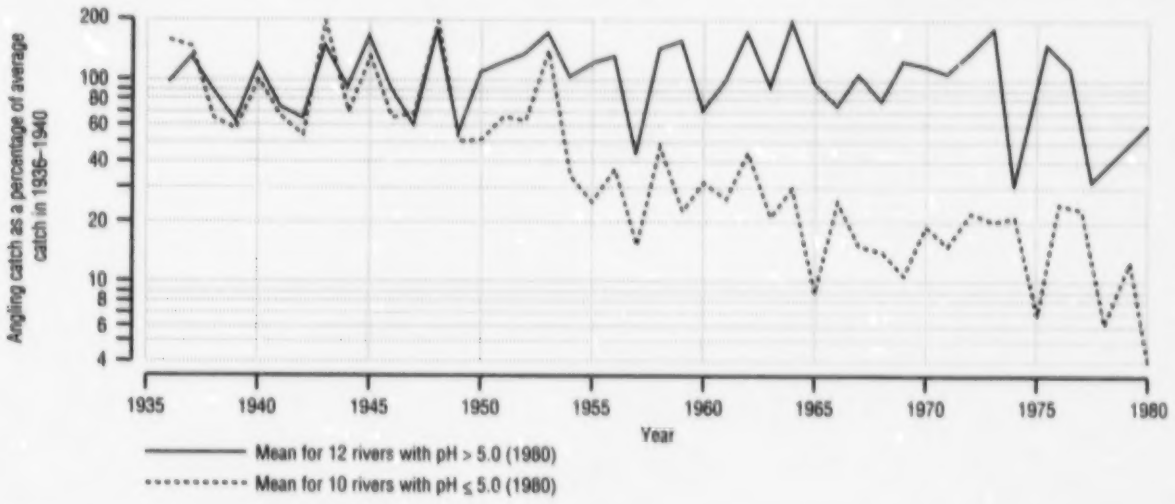
SOURCE: RMCC 1990.

a program to reduce the 1980 regulated value of 4.6 million tonnes of sulphur dioxide in eastern Canada by 50% to 2.3 million tonnes, to be reached in a series of control steps ending in 1994. This program is well advanced: one company has a substantial control facility under construction, and other large companies are in the process of implementing their specific control programs so that the emissions reductions will be accomplished by 1994. Ontario Hydro recently announced that its control program will cost between $3 billion and $5 billion, depending on the rate of growth of electricity use, and this will add approximately 3% to the electricity rates.

In response to the well-established scientific understanding of the sulphur dioxide acidification problem, Canada has acted decisively in controlling sulphur dioxide. In addition, Canada has moved to reduce the oxides of nitrogen by introducing pollution controls on light-duty vehicles in September 1987 and on heavy-duty vehicles in December 1988. The provincial control order applied to Ontario Hydro's thermal-powered generating stations specifies total acid gas emissions, thus requiring limits on both sulphur dioxide and nitrogen oxide emissions. As a result, Ontario Hydro has been installing special burners at its power plants to reduce the formation of oxides of nitrogen in order to meet these requirements.

Both Canada and the United States have reduced sulphur dioxide emissions considerably. In some areas downwind of pollution sources, there are signs of recovery of aquatic ecosystems, but the areas that continue to receive too much deposition are not recovering and continue to deteriorate. In Canada, this is explained by the wide differences in the buffering capacity of surface waters. However, there have been improvements in some rivers in Nova Scotia and Newfoundland (Table 9), which corre-

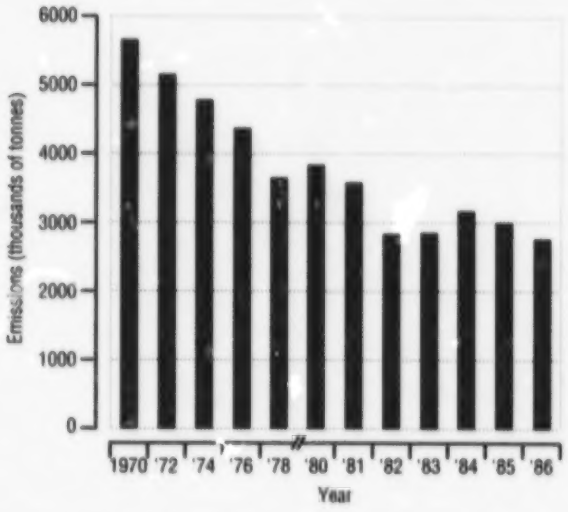
Figure 32
Trends in Atlantic salmon catch, 1936–1980



SOURCE: Watt *et al.* 1983.

NOTE: Angling data are normalized to facilitate the comparison between high- and low-pH rivers. Each river's catch was expressed as a percentage of the mean catch in 1936–1940 so as to give all rivers equal weighting, and the two groups were then averaged by year.

Figure 33
Sulphur dioxide emission trends in eastern Canada, 1970–1986

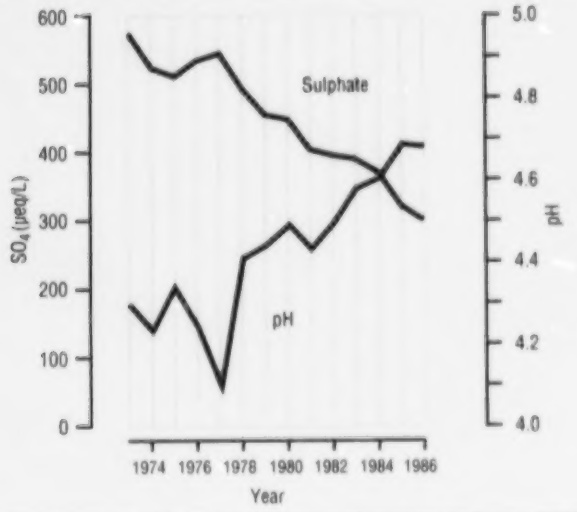


SOURCE: Vena 1989.

spond to the decrease in sulphur dioxide emissions and in the amount of sulphate that is exported from the watershed. Improvements have also been observed in some lakes in the Sudbury district (Figure 34); scientific evidence such as that presented in Figure 34 supports the contention that reduced sulphur dioxide emissions led to the predicted improvements.

Although environmental damage due to sulphur deposition is well documented, damage from nitrogen deposition appears to be minimal in Canada at current deposition levels. Nevertheless, in recent years, scientists have been paying more attention to potential problems and to developing scientifically defensible nitrate deposition targets. These targets would be the basis for any long-term controls on emissions. Canada's position now is that a freeze on nitrogen oxides emissions at 1987 levels is justifiable until scientific studies provide better information on long-term target loads.

Figure 34
Trends in sulphate concentration and acidity in Clearwater Lake near Sudbury, Ontario, 1973–1986



SOURCE: Dillon *et al.* 1986.

NOTE: Results are whole-lake annual averages.

Pollutants in the Arctic atmosphere

Historically, the Arctic has been perceived as having clean air, but observations over the past few years have confirmed that, indeed, there are pollutants in Arctic air. Man-made pollution that reaches the Arctic and causes a reduction of visibility has been labelled *Arctic haze*. It has its origins mainly in Asia and Europe and, to a lesser extent, in North America. The term was first coined in a publication in the 1950s (Mitchell 1957) in which it was reported that Arctic haze was due to particles no larger in diameter than 2 μm, that it was observed in patches of 800–1300 km across, and that it occurred at all levels of the atmosphere below 9 km from Earth's surface. The concern for Arctic haze did not resurface until the 1970s, when high values of atmospheric turbidity were observed in the Arctic. The turbidity of the atmosphere is a measure of reduction of direct solar radiation due to particulate matter. With this impetus, our scientific understanding of this phenomenon has progressed significantly in the past five years compared with the previous 25 years (Barrie 1986).

When the air is clear, one can theoretically see as far as 200 km through the atmosphere. The haze caused by the pollutants in the air can decrease this distance to less than 50 km. The acidity of snow on the Agassiz glacier on Northern Ellesmere Island is well correlated with depth of measurement and shows a strong seasonal variation paralleling that of Arctic air pollution—i.e., maximum acidity in a year occurs at the peak of Arctic air pollution (Barrie 1985). A comparison of the historic record of maximum ice core acidity with that of sulphur dioxide emissions in Europe and in the western Soviet Union during this century has confirmed this correlation (Barrie *et al.* 1985).

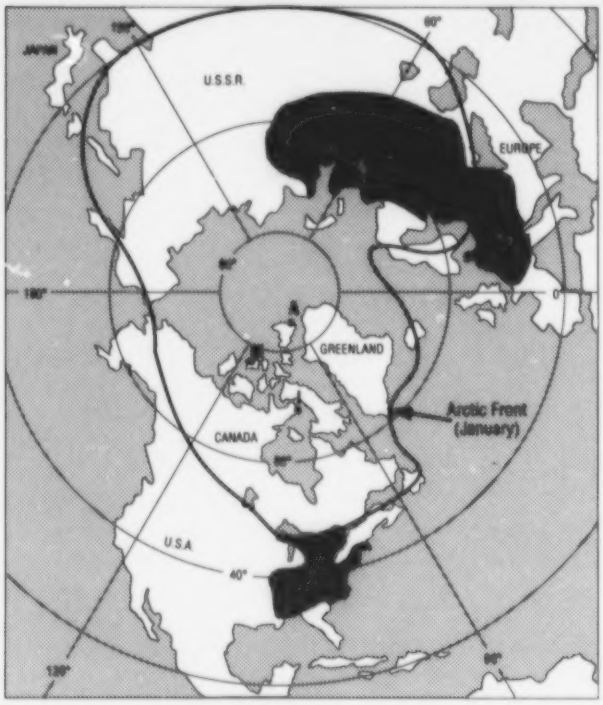
Table 9
Changes in sulphur dioxide emissions in eastern Canada and the northeastern United States, yearly export of sulphate from watersheds, and pH of rivers

Parameter	1971–1973	1982–1984	Change
Annual sulphur dioxide emissions (averages in millions of metric tonnes)	27	20	–25%
Watershed export (kg SO_4/ha per year)			
—Nova Scotia	39	21	–47%
—Newfoundland	32	18	–44%
Median pH for the rivers			
—Nova Scotia	4 4–6.5	4.5–6.7	
—Newfoundland	5.5–7.7	6.1–7.8	

Because of the characteristics of the Arctic air mass in summer and winter, the problems of the Arctic are unique. Figure 35 shows the main sources of air pollution in the northern hemisphere that have a bearing on the quality of the Arctic air. The typical edge of the Arctic air mass for the month of January when the pollution is at its peak is also shown in the figure. In winter, prevailing winds pick up pollution and transport it northward in the Arctic air mass. Pollution from the eastern area of North America is generally carried eastward over the stormy North Atlantic and, therefore, does not affect the Arctic air mass to a large extent. In summer, the south–north transport is weak and cloud cover in the Arctic is high, leading to minimum pollution.

In the atmosphere, the haze occurs as an aerosol that contains approximately one-third sulphate compounds, one-third soot and hydrocarbons, and one-third natural oceanic and soil material. The sulphate suspended in the air as particles consists of sulphuric acid and ammonium sulphate. The ammonium sulphate is produced when sulphuric acid reacts with ammonia. Soot is produced from the combustion of fossil fuels, such as oil, coal, and wood. The weekly average concentration of sulphate, originating from industrial activities farther south, has been found to be 20 to 40 times higher in winter than in summer (0.1 μg/m³). On the average, the sulphate concentrations measured in the winter haze are only a factor of 2 to 3 lower than those measured in rural areas of eastern Canada and the United States.

Figure 35
The position of the Arctic air mass in January



SOURCE: Environment Canada 1984.

NOTE: Pollution is at its peak in the Arctic in January. Shading shows pollutant source areas. A characteristic of the Arctic air mass is that pollutants persist much longer in winter than in summer. Canadian Arctic air monitoring stations: M—Mould Bay, Northwest Territories; A—Alert, Northwest Territories; I—Igloolik, Northwest Territories.

Besides the observed change in visibility, this pollution is postulated to affect the climate and the Arctic ecosystem. The presence of soot-bearing, man-made particulate matter in the Arctic air increases the amount of solar radiation trapped in the troposphere. Also, the increased blackness of the top layers of the snow covering the ground, the snowpack, absorbs solar radiation. These two factors change the in-going and out-going radiation and potentially can modify northern hemispheric climate. Measurements of the snow falling in the winter indicate that it is slightly acidic, between pH 4.9 and 5.2. As has been observed in the initial melting of the snowpack, leaching of acidic constituents can occur, and, therefore, this water can be several times more acidic than the snowpack.

Arctic air pollution is also a vehicle for potentially toxic substances released at mid-latitudes and deposited in the Arctic. These substances include metals, such as mercury, and herbicides or pesticides. Their accumulation in Arctic ecosystems and in the foods of our native populations is of concern.

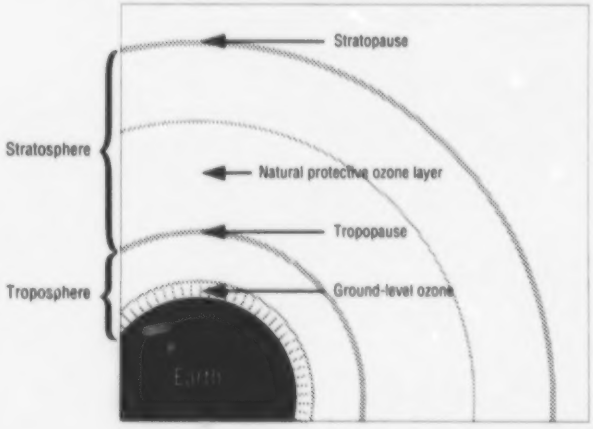
Global issues

Stratospheric ozone depletion

The stratosphere, a region of the atmosphere extending from a height of about 11 to 47 km above the Earth's surface, is relatively stable and is stratified, because the temperature of stratospheric air increases with height (Figure 36). The temperature in the stratosphere is enhanced primarily because of the presence of ozone, a gas that absorbs solar and terrestrial radiative energy. About 90% of the atmospheric ozone occurs in a layer in the stratosphere extending in height from the tropopause, the region at the top of the troposphere, to about 40 km, with a peak near 22 km. The total amount of atmospheric ozone in a column over the Earth's surface compressed to ground-level pressure and temperature would normally measure between 2 and 5 mm in depth, depending on latitude and time of year.

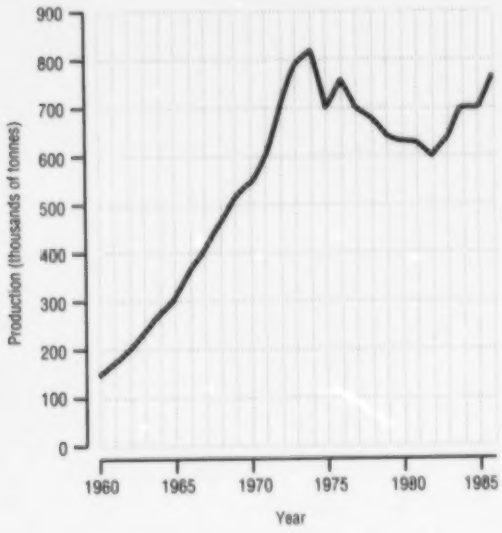
The presence of ozone in the stratosphere has two important consequences relevant to environmental issues. First, the temperature structure of the stratosphere depends on the amount of radiative energy absorbed by ozone. The stratospheric temperature structure influences the general

Figure 36
Ozone in the atmosphere



NOTE: The height of the troposphere varies with latitude.

Figure 37
Global production of chlorofluorocarbons



SOURCE: Environment Canada 1988*b*.

circulation and climatology of the atmosphere. Second, the amount of damaging solar ultraviolet-B radiation transmitted through the atmosphere to the Earth's surface depends on the amount of ozone. Increased ultraviolet-B radiation is detrimental to human health by causing a suppression of the immune system, premature skin aging, and increased occurrences of sunburn, skin cancer, and cataracts. Yield from such crops as wheat, rice, corn, and soya beans would decrease with an increase of ultraviolet-B radiation. Growth rates of forests and aquatic life near the surface of the ocean would be disrupted by a change in the amount of this type of radiation. Synthetic plastic materials degrade more rapidly with increased exposure to this radiation.

There has been significant concern over the past two decades that some of man's activities may deplete the stratospheric ozone layer. In the early 1970s, it was predicted that stratospheric ozone is vulnerable to chlorofluorocarbons (CFCs), a family of chlorine-containing man-made gases that are commonly used both domestically and industrially. Chlorofluorocarbons are stable, nontoxic chemicals that remain in the atmosphere until they are photolysed by harsh ultraviolet sunlight found only above the ozone layer, to yield chlorine. One molecule of chlorine has the potential to destroy catalytically one million molecules of ozone before leaving the atmosphere.

Measurements of ozone and other related chemical gases indicate that these early predictions of ozone depletion are indeed occurring. The concentration of ozone over Toronto, for example, has decreased by about 4% since the mid-1970s. The most striking observation is the 50% decrease in ozone levels over the Antarctic during October of each year since the mid-1970s. Extensive studies of this Antarctic ozone "hole" have indicated that the ozone is destroyed by large amounts of chlorine.

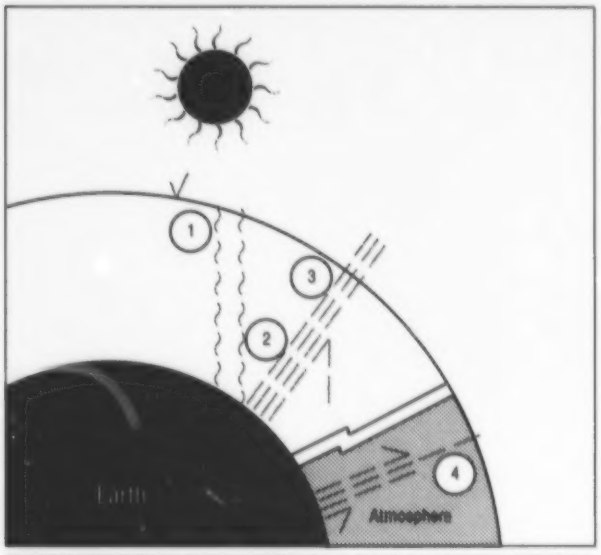
Chlorofluorocarbons have been used as a coolant in refrigerators and air conditioners, as a propellant in aerosol spray cans, as a blowing agent to manufacture foams, and as a cleaning solvent. Restriction of the use of CFCs in spray cans in North America in the 1970s resulted in a temporary decrease in the world production of CFCs. However, continued use for other applications has reversed this downward trend (Figure 37). The continued usage of CFCs, combined with the increased evidence that CFCs are depleting the ozone layer, has prompted the United Nations Environment Programme to reduce the global production of CFCs through the Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol on Substances that Deplete the Ozone Layer.

Climate change—global warming

Earth's climate is ideally suited for life. It supports a wide range of natural ecosystems, each attuned to local availabilities of moisture and heat. Major changes have occurred in the past, but these changes have never exceeded the limits beyond which life could no longer adapt and survive. A primary reason for this life-supporting climate system is the presence within the atmosphere of minute amounts of a number of important gases popularly referred to as "greenhouse gases," which collectively behave as an insulating blanket around the planet. Their effect on the incoming solar radiation, which fuels the Earth's climate system, is minimal. However, their combined influence on the outgoing longwave radiation emitted from the Earth's surface and lower atmosphere towards space is substantial. By absorbing and returning much of this outgoing radiation, they effectively trap heat within the lower atmosphere. This "greenhouse effect" is naturally occurring and essential to the maintenance of a livable climate on Earth (Figure 38). Without it, the Earth's surface would be 30°C colder.

With the accumulation of 30 years of accurate measurements of the concentration of carbon dioxide—the most important and most abundant greenhouse gas—the evidence is clear that human activities are changing the planetary atmosphere. The amount of carbon dioxide in the atmosphere has increased 10% since 1958 (Figure 39) and is increasing at a rate of 0.4% per year. This represents an

Figure 38
The "greenhouse effect"



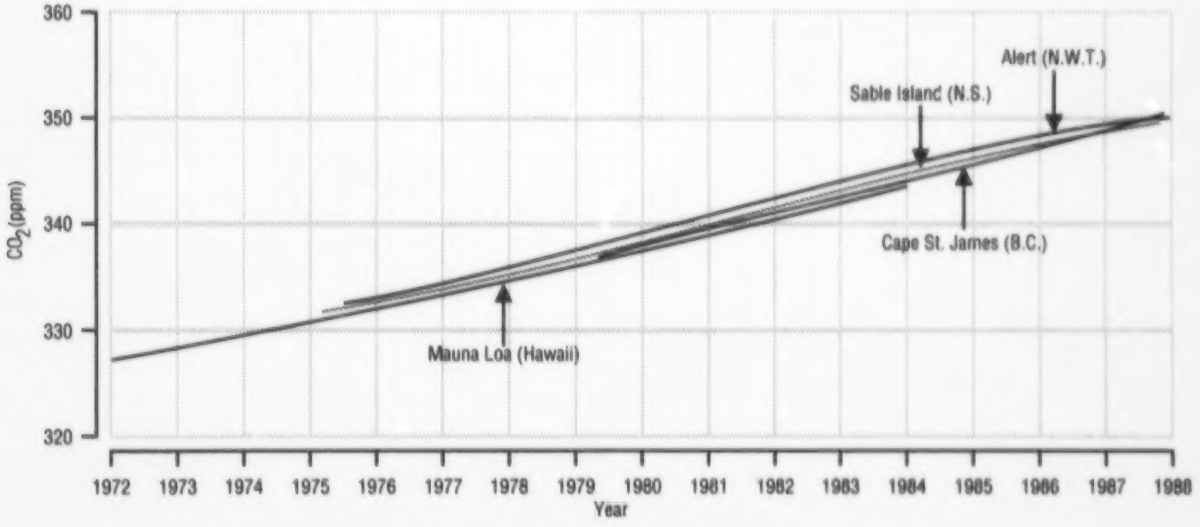
SOURCE: Environment Canada 1988c.

1 — Solar energy enters the atmosphere unaffected by greenhouse gases.
2 — Solar light is absorbed by the Earth and reradiated back to space at longer heat wavelengths.
3 — Greenhouse gases absorb heat radiation and reradiate much of it back to the surface, much like an insulating blanket.
4 — Higher concentrations of greenhouse gases trap more reradiated heat, causing temperatures in the lower atmosphere and at the surface to rise. This affects weather and climate.

increase of about 25% in carbon dioxide concentration since preindustrial periods. Atmospheric methane, also a very effective greenhouse gas, is increasing by about 1% per year and has almost doubled in concentration during the past several hundred years. The rising global population of domestic animals and increased land area used for rice paddies are important sources of methane and suggest that increases in atmospheric concentrations will continue. Concentrations of other greenhouse gases, such as nitrous oxide, ozone, and CFCs, are also increasing. Primary causes of increased greenhouse gas concentrations are the rapid rise in global population, the increased consumption of coal, oil, and gas, deforestation, agriculture, land use changes, and industrial processes.

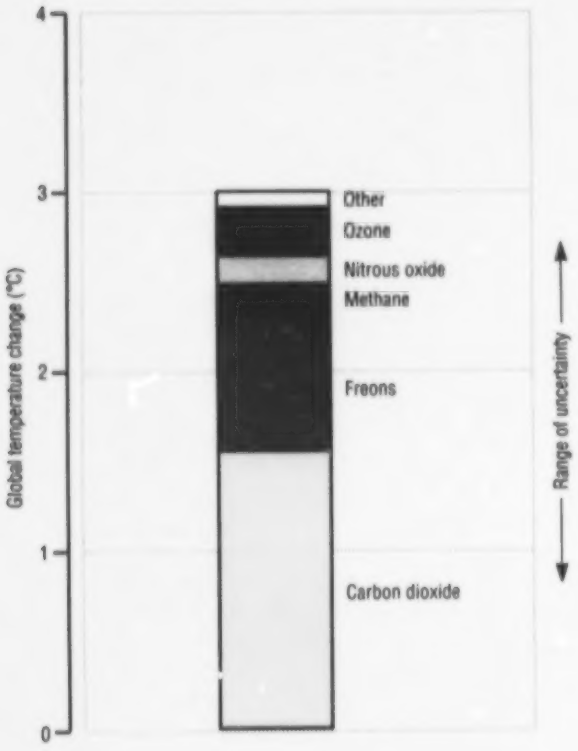
Carbon dioxide emissions from the burning of fossil fuels for energy appear likely to escalate at an average rate of about 1% per year until at least 2050. These projections of future emissions of carbon dioxide and other greenhouse gases into the atmosphere indicate that, at a minimum, there could be an enhanced greenhouse effect equivalent to the doubling of carbon dioxide concentrations in the atmosphere from those in the preindustrial era. The timing of such an enhancement is uncertain, but it appears possible that it will occur as early as 2030 and probably by 2050. Atmospheric scientists now agree that a major climate warming greater than any yet experienced by humans is likely to occur. Recent studies suggest that the average surface temperatures

Figure 39
Increases in atmospheric carbon dioxide levels



SOURCE: Environment Canada 1988c.

Figure 40
Global warming



SOURCE: Environment Canada 1988c.

of the Earth may increase by 3.0°C with an enhanced greenhouse effect equivalent to the doubling of the carbon dioxide in the atmosphere (Figure 40). Such warming would probably be accompanied by amplified warming in high-latitude regions in both autumn and winter, by drier summers in mid-latitudes of the northern hemisphere, by increased moisture availability in polar regions, and by a possible mean global rise in sea level of about 1 m.

In Canada, some of the specific effects of global warming that are predicted are as follows:

- Agriculture will likely benefit from warmer and longer growing seasons, particularly in northern regions.
- Field crop growth could be enhanced up to 15% as a result of increased carbon dioxide levels.
- Agriculture in southern regions may be affected by increased frequency and severity of drought, and some areas of the plains may become desert.
- Great Lakes winter ice seasons may disappear.
- Decreased Great Lakes Basin runoff could reduce traditional lake levels by 80 cm.
- Ecological marshes, such as Point Pelee, would disappear or be significantly altered.
- Reliable snow seasons could disappear in southern Ontario.

Responding to the effects of climate change is not a new problem for humans. Like natural ecosystems, they have attuned their behaviour and lifestyles to the characteristics of regional climates. Now that it is realized that man is able to change his environment by his activities, a new dimension is added to the climate/society relationship. The Earth's system is complex. We still do not adequately understand how it works and how changes we are making to the atmosphere alter it. This presents an unprecedented challenge to the international scientific community. Until recently, the debate about how humans are changing the structure and the composition of the atmosphere has been a scientific one. As our understanding of the implication of these changes increases, the issue is progressively becoming a major concern of policy makers.

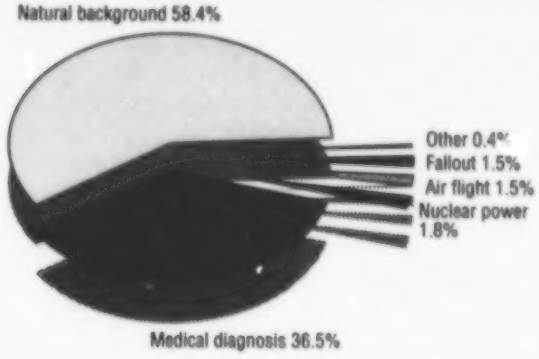
Atmospheric radioactivity

People are exposed to radioactivity from a variety of sources. These sources include medical X rays and diagnostic tests, natural sources such as cosmic radiation and naturally occurring elements such as uranium and radon, fallout from nuclear weapons tests, and nuclear power production. More than 95% of the average radiation dose experienced by Canadians today is due to medical and natural sources (Johnson and Tutiah 1985). Figure 41 shows the breakdown of exposure by source.

The primary health concern associated with exposure to radioactivity is cancer (UNSCEAR 1977). Research has demonstrated that the risk of cancer increases as exposure to radioactivity increases. However, exposure to natural sources of radioactivity, the so-called "background" radioactivity, is a part of everyday life. Therefore, exposure to man-made radioactivity (such as medical X rays or fallout) is always compared with background levels as a benchmark.

From 1945 to 1962, the United States, the Soviet Union, and Great Britain conducted 356 atmospheric tests of nuclear weapons (UNSCEAR 1982). They stopped testing in 1962, and the Nuclear Test Ban Treaty took effect in 1963. Between 1960 and 1980, China and France conducted 67 tests (UNSCEAR 1982).

Figure 41
Proportion (%) of radiation dose as a function of source



SOURCE: AECL 1985.

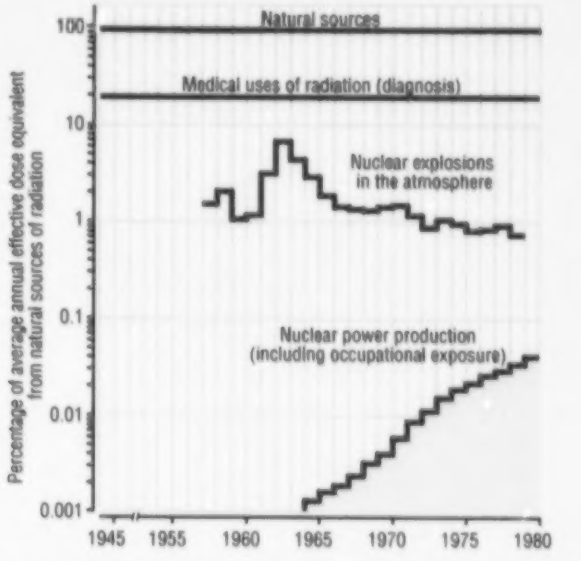
Most nuclear weapons tests were conducted in the northern hemisphere; as a result, the northern hemisphere received approximately three times as much fallout as the southern hemisphere (UNSCEAR 1982). The greatest accumulation of fallout settled between 40 and 50°N latitude (UNSCEAR 1977). Thus, fallout in Canada was greatest in the southern part of the country.

Figure 42 depicts estimated worldwide average annual dose of radiation from various sources of exposure as a percentage of natural (background) sources. It is apparent that the dose resulting from the fallout of nuclear weapons tests has now dropped to less than 1% of natural sources.

The 1986 explosion at a nuclear power plant in Chernobyl, USSR, commanded worldwide attention, as radioactivity was widely dispersed in the northern hemisphere, predominantly over Europe. It was found that Chernobyl had very little impact on the level of radioactivity in the atmosphere over Canada; although the Chernobyl accident caused a slight, temporary increase in the level of radioactivity as monitored across Canada, the effect was short-lived, with levels dropping quickly to pre-Chernobyl levels.

In Canada today, exposure to radioactivity now in the atmosphere is less than 0.2% of that experienced during the peak years of atmospheric nuclear weapons tests. The atmospheric radioactivity now detected is virtually all due to natural sources, with levels of fallout radionuclides, such as cesium-137, being below limits of detection of the air samples.

Figure 42
Trends with time of doses from different sources of radiation



SOURCE: UNSCEAR 1982.

NOTE: Worldwide annual doses are expressed as a percentage of the average exposure to natural sources.

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Chapter 6

Public and government responsibility

Public perception of the air pollution problem

Air pollution is not a newly recognized phenomenon. The progress that has been made to control it over the past two decades is in part a reflection of an emerging change in societal perception with roots in the unrest and protests of the 1960s. Early visions of unlimited growth, especially unlimited technological growth, were questioned. There was a growing awareness that, under a regime of unlimited growth, both society and the environment were suffering a loss of identity and were vulnerable to such abuses as air pollution. An uneasiness has been created by the observation that the atmosphere is changing because of pollution, largely to the detriment of society, if theories and predictions are right. More importantly, the atmosphere is perceived to have changed significantly within the life span of one or two generations.

The vehicles we drive

The most common types of vehicles driven today are passenger cars and light-duty trucks, which together comprise over 88% of the vehicles on our roads and highways. The automotive industry has responded to the requirement to produce vehicles that do not emit excessive amounts of pollutants, to the extent that the average emissions performance of new cars has consistently been 20–30% better than what pre-1987 emissions standards specified.

On the surface, then, it would appear that the problem of motor vehicle pollution should continue to lessen through attrition, as most motor vehicles in use are less than 10 years old. As older vehicles are retired, a larger percentage of vehicles that meet emissions standards will be driven. The flaw in this reasoning, of course, is that manufacturers' performance specifications are not always maintained once the motor vehicles are in the hands of the consumers. Motor vehicles are not always serviced and repaired adequately. Pollution control devices are sometimes deliberately tampered with or even removed in the mistaken belief that in doing so fuel consumption will drop or the vehicle will develop more power (Cope 1988). Indeed, study results show that about 66% of in-use vehicles tested between 1974 and 1983 had excessive emissions (Gourley *et al.* 1985). Misfuelling—the term used to describe the practice of using leaded gasoline in motor vehicles designed to run on unleaded gasoline—also leads to increased emissions. The lead from the gasoline quickly contaminates the vehicle's catalytic converter, rendering it almost useless.

One way to deal with tampering and misfuelling is through public education programs. A second step is to introduce antimisfuelling and antitampering legislation to reinforce the importance of eliminating these practices. Legislation of this nature is a provincial responsibility in Canada, and so far only Ontario, Quebec, and Newfoundland have antitampering legislation, although British Columbia has an antitampering provision in its Motor Vehicle Act (Cope 1988). One means to enforce this legislation is to introduce motor vehicle inspection and maintenance programs whereby vehicles are inspected periodically and owners are compelled to have any necessary repairs performed as a prerequisite to licence renewal. There are no inspection and maintenance programs in Canada, but Ontario and British Columbia are considering implementing them.

At the federal level, a two-year publicity campaign was undertaken in 1989 in partnership with the Petroleum Association for the Conservation of the Environment to warn the public of the dangers of misfuelling and the benefits of proper vehicle maintenance. The purpose was to attempt to make the public, automobile dealers, and mechanics aware of the benefits of following the manufacturers' specifications. The federal government will also introduce regulations that will effectively eliminate leaded fuel from retail gasoline stations in 1990, thus preventing misfuelling.

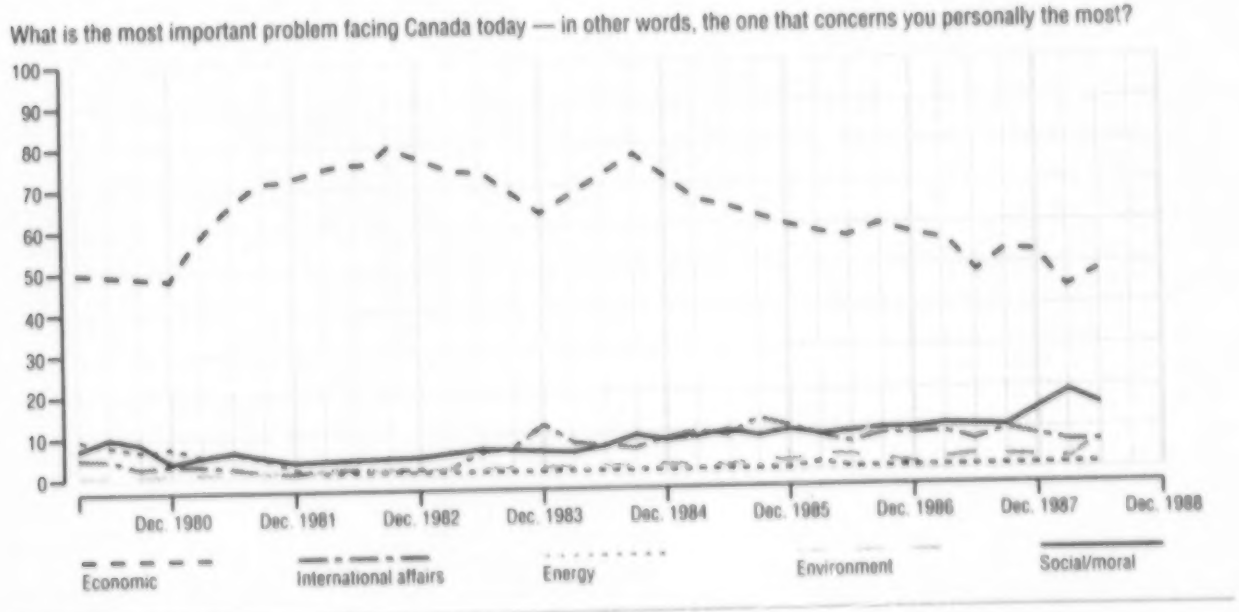
The role of the public and of public institutions in solving air pollution problems is fundamental. Most forms of air pollution are directly related to consumer demands and lifestyles that ignore environmental consequences. Gaining public support, explaining choices to be made, and securing public involvement are essential. Economists have a vital role to play, for environmental issues are economic issues. There is a need to identify economic solutions, and questions of cost and who will bear that cost must be answered.

The consequences of air pollution are not fully understood, but undesirable health and environmental effects are predicted. It is, therefore, not astonishing that headlines such as some of those reproduced on page 4 of this report have caused alarm, and perhaps some confusion, and have led to public outcries for government action to prevent pollution of the atmosphere. Public opinion polls continually show that environmental issues such as atmospheric pollution rank high in the minds of the public. The number of Canadians identifying environmental issues as the nation's most serious problem rose sharply to 7% between March and June 1988 (Figure 43) according to a survey (Decima Research 1988). This is the first time this decade that the figure has been above 3%. The survey was conducted before the World Conference on the Changing Atmosphere in June 1988 in Toronto and before the fire at the facility for storage of polychlorinated biphenyls (PCBs) in St-Basile-le-Grand, Quebec, in August 1988.

The environmental issues addressed in the survey of public opinion were as follows:

- air pollution
- damage to Earth's atmosphere
- industrial and chemical waste disposal
- acid rain
- pollution of lakes, rivers, and streams
- spills of hazardous material
- loss of recreation land and parkland
- pollution from leaded gas
- oil spills
- contamination of drinking water
- use of chemical pesticides and fertilizers on food crops
- loss of usable farmland to development
- use of chemical pesticides on forest resources

Figure 43
Survey results on Canada's most important problems



SOURCE: Decima Research 1988.

Federal control of motor vehicle pollution in Canada

The Government of Canada limits the amount of carbon monoxide, unburned hydrocarbons, oxides of nitrogen, and particulate matter that may be emitted by new light-duty motor vehicles offered for sale in Canada. It also limits emissions of the same pollutants from heavy-duty engines, such as those used in trucks and buses. Vehicle emissions standards are established by regulations under the Motor Vehicle Safety Act, which is administered by Transport Canada, and have been in effect since 1 January 1971. The Canadian standards are "self-certified" by the vehicle manufacturer and audited by government laboratories.

Canada has now amended its passenger car and light-duty truck standards to parallel those in the United States, effective for vehicles built on or after 1 September 1987, and has amended heavy-duty vehicle standards effective for vehicles built on or after 1 December 1988 (Table 10). The new light-duty vehicle standards that became effective on 1 September 1987 are forecast to reduce light-duty vehicle emissions by the year 2005 by 25% for oxides of nitrogen, 41% for volatile organic compounds, and 30% for carbon monoxide, from 1985 levels. The heavy-duty vehicle emissions standards that became effective on 1 December 1988 are forecast to reduce heavy-duty vehicle emissions by the year 2005 by 9% for hydrocarbons and 30% for carbon monoxide. Emissions of oxides of nitrogen are predicted to increase because of a substantial increase in the number of heavy-duty diesel-powered vehicles. The standards for heavy-duty vehicles with diesel engines that became effective on 1 December 1988 can reduce heavy-duty emissions of oxides of nitrogen by 15% and particulates by 15%. These standards for heavy-duty gasoline- and diesel-powered vehicles are parallel to those that came into effect for the 1988 model year in California and will come into effect in 1990 in the rest of the United States.

The concentration of fuel additives in gasoline was controlled by regulations under the Clean Air Act administered by Environment Canada and continues to be controlled under the new Canadian Environmental Protection Act. Demand for unleaded gasoline, which has been available in Canada since 1971, grew from about 6% in 1975 to 45% in 1983 and was approaching 70% in May 1988. The content of lead antiknock additives has been reduced progressively to its present limit of 0.29 g/L as of 1 January 1987. The government intends to effectively eliminate leaded gasoline by 1 December 1990. Limited sales of gasoline of low lead content will be allowed for special use, such as in farm and marine equipment.

Canada will begin a comprehensive regulatory impact analysis of adopting US 1994 heavy-duty vehicle standards as well as more stringent controls for light-duty vehicles and fuels. This analysis will assess opportunities to reduce the contribution of internal combustion engines to increasing levels of ground-level ozone, carbon dioxide, and toxic air pollutants, as well as to acid rain.

The analysis will be broad, examining ways to reduce emissions from internal combustion engines in motorcycles, cars, trucks, railway locomotives, and marine vessels, as well as the engines used in construction, agriculture, and other industries. The fuels that these engines use will also be studied to determine how changes to their properties and composition will influence the type of emissions. For example, gasoline volatility controls can significantly reduce summertime hydrocarbon losses from vehicles by evaporation, which contribute to ground-level ozone production.

According to the survey, the vast majority of Canadians believe that their own and their family's health are affected by environmental problems. Among the 13 environmental issues specified in the survey, those relating to water quality, waste management, and air quality were the issues of most personal concern to Canadians. However, air pollution was the issue most strongly associated with general concern about both environmental quality and human health.

Public opinion on the environment/economic growth question has changed significantly since the 1960s. According to another opinion poll, 83% of Canadians now believe that there is no conflict between economic growth and the environment, a perception that has led to the concept of "sustainable development."

Over the past two years, there has been a marked shift in the perceived responsibility for protection of the environ-

Table 10
Motor vehicle emissions control standards in Canada[a]

Motor vehicle	Effective date	Oxides of nitrogen	Carbon monoxide	Hydrocarbon	Particulate
Automobiles	Up to 31 August 1987	1.93	15.54	1.24	NS[f]
	1 September 1987 and beyond	0.62	2.11	0.25	0.12
Light-duty trucks					
0–6000 lb (0–2730 kg) GVWR[b]	Up to 31 August 1987	1.93	15.54	1.24	NS
0–8500 lb (0–3860 kg) GVWR	1 September 1987 and beyond	0.75[c]/1.1[d]	6.2	0.50	0.16
Heavy-duty trucks					
Over 6000 lb (2730 kg) GVWR	1975 to 30 November 1988	5.87[e]	14.66	5.87[e]	NS
8500–14 000 lb (3860–6360 kg) GVWR	1 December 1988 and beyond				
— gasoline		2.20	5.28	0.40	0.22
— diesel		2.20	5.69	0.48	0.22
14 000 lb (6360 kg) GVWR and over	1 December 1988 and beyond				
— gasoline		2.20	13.62	0.70	0.22
— diesel		2.20	5.69	0.48	0.22

[a] Units are in grams per kilometre for automobiles and light-duty trucks, and grams per megajoule for heavy-duty trucks.
[b] Gross Vehicle Weight Rating.
[c] Oxides of nitrogen standard applies to 1705 kg loaded vehicle weight or less.
[d] Oxides of nitrogen standard applies to over 1705 kg loaded vehicle weight.
[e] Total grams of oxides of nitrogen and hydrocarbons emissions per megajoule.
[f] NS = No standard.

Common air pollutants for which national air pollution emissions guidelines have been issued under the Clean Air Act*

Pollutants	Guideline applicable to
Particulate matter	• Cement industry
Particulate matter	• Asphalt paving industry
Particulate matter Sulphur dioxide	• Metallurgical coke manufacturing industry
Particulate matter Sulphur dioxide	• Arctic mining industry
Particulate matter Hydrogen chloride Sulphur dioxide	• Packaged incinerators**
Particulate matter Total reduced sulphur compounds Sulphur dioxide	• Wood pulping industry (new stationary sources)
Nitrogen oxides Particulate matter Sulphur dioxide	• Thermal power generation (new stationary sources)

* In 1988, the Canadian Environmental Protection Act was proclaimed, subsuming the Clean Air Act.
** Any furnace used in the process of burning solid waste whose maximum burning rate does not exceed 900 kg of solid waste per hour.

Toxic air pollutants regulated under the Clean Air Act*

Pollutant	Regulation applicable to	Human health concern
Lead	Secondary lead smelters	• neurological damage in children • depressed hemoglobin production • kidney damage • increased mortality rate
Mercury	Mercury cell chlor-alkali plants	• neurological damage
Asbestos	Mines and mills	• tumour formation
Vinyl chloride	Vinyl chloride and polyvinyl chloride	• a rare form of liver cancer

* In 1988, the Canadian Environmental Protection Act was proclaimed, subsuming the Clean Air Act.

ment, with a stronger role seen for individuals. The primary responsibility, nevertheless, is still envisioned as resting with governments.

Government legislation on air pollution

Prior to the 1970s, adequate national legislation and a mechanism to coordinate federal and provincial efforts to counter air pollution were lacking, and provincial and municipal legislation varied across the country (Powell and Wharton 1982). The federal government's jurisdiction over the control of air pollution in Canada was largely in the areas of sole federal authority under the powers granted by the Constitution Act of 1867—navigation and shipping, public harbours, railways, public works, and Crown corporations. Provincial governments focused their attention on air pollution from industry and commercial enterprises within their jurisdictions. Pollution from the uncontrolled release of smoke and other combustion products was the principal concern of both levels of government. Sulphur fumes from smelters, pulp mills, and oil refineries; hydrogen sulphide from natural gas recovery; hydrocarbons from the petrochemical industry; dust from iron and steel plants; pollutants of all kinds from incineration of garbage—all these were problems to be resolved by provincial and municipal authorities.

In the early 1970s, there was general recognition of the value in having federal and provincial governments act in a uniform way to control air pollution. In 1970, the Motor Vehicle Safety Act was passed, providing the authority to regulate emissions from all new motor vehicles, and tax incentives to reduce or prevent air pollution were instituted under Income Tax Act regulations. In 1971, the federal Clean Air Act was passed, the same year in which the federal Department of the Environment was formed. The Clean Air Act was designed to promote uniformity, to assist provincial governments in developing legislation and control programs, and to give the federal government regulatory authority to protect human health, regulate the composition of fuels, and gather information on sources of air pollution in Canada.

Between 1971 and 1988, the Clean Air Act was used to prescribe national air pollution emissions regulations for stationary sources of air pollutants, national emissions guidelines for both stationary and mobile emissions sources (which the provinces can use), national ambient air quality objectives, and fuel composition regulations. The Motor Vehicle Safety Act was used to regulate emissions from motor vehicles.

Chronology of some past events of significance for air pollution

1872	Term "acid rain" first used in England
1920s	Chlorofluorocarbons developed
1952	First report of Arctic air pollution
1952	4000 excess premature deaths from air pollution in London, England
1956	First clean air legislation in Canada (Ontario)
1962	Acid rain issue raised by Sweden at United Nations conference (Stockholm)
1971	Environment Canada formed
1971	Clean Air Act passed
1973	First world oil crisis
1974	Lead-free gasoline introduced
1975	Light-duty vehicle emissions standards introduced
1976	Lead content of leaded gasoline lowered
1978	Second world oil crisis
1980	Canada–US Memorandum of Understanding on Transboundary Air Pollution
1982	Sulphate deposition target of 20 kg per hectare established
1984	Federal–provincial commitments to reduce sulphur dioxide emissions in eastern Canada
1985	International sulphur dioxide abatement protocol signed
1986	Vienna Convention for the Protection of the Ozone Layer
1987	Montreal Protocol on Substances that Deplete the Ozone Layer
1987	More stringent light-duty motor vehicle standards imposed
1987	Lead content of leaded gasoline lowered
1988	Canadian Environmental Protection Act passed
1988	Heavy-duty motor vehicle emissions standards in effect
1988	Toronto International Conference on the Changing Atmosphere
1988	International oxides of nitrogen protocol signed

Prior to 1988, the legislative authority for environmental protection was found in the provisions of a number of federal environmental statutes. On 30 June 1988, the Canadian Environmental Protection Act (CEPA) was proclaimed, which consolidates the environmental protection provisions of the Clean Air Act and four other Acts and provides added authority needed to prevent pollution. The new Act is multimedia in nature—i.e., it does not limit authority to a single environmental medium, such as air. Rather, it reflects the need to prevent substances from entering any component of the environment if that substance is likely to cause harm anywhere in the environment. As well, the new Act, unlike the Clean Air Act, focuses on both protection of human health *and* protection of the environment. All of the regulations, guidelines, objectives, and codes of practice brought into effect between 1971 and 1988 under the Clean Air Act will remain in effect under CEPA.

Under CEPA, a list of 44 substances, called the Priority Substances List, was published in February 1989 (Environment Canada 1989). This list was based on a recommended list of candidate priority substances identified by an Advisory Panel to the Ministers of the Environment and of National Health and Welfare. The Priority Substances List identifies substances with potential to harm human health and the environment, irrespective of whether they are air pollutants, water pollutants, or solid wastes, and these substances will be priorities for assessment over the next five years. An assessment will determine if a substance is "toxic" as defined in the Act—i.e., if a substance inherently constitutes a danger to both the environment and human life and health—and whether the substance is now entering or is likely to enter the environment. Many of the substances on the list are classes of compounds, so the list effectively comprises hundreds of individual compounds, many of which are air pollutants. Complementing this initiative—because there are other toxic air pollutants that are not on the CEPA priority list—the Federal–Provincial Advisory Committee on Air Quality, which advises federal and provincial environment ministers in Canada on air pollution matters, has been directed to look specifically at toxic air pollutants in Canada and to identify what it considers the priorities to be.

Conclusions

How has the air come to be as polluted as it is today?: partly through neglect and prolonged inaction on obvious problems, partly because predicted impacts of pollutants on the environment often take decades to manifest themselves, and partly because the tools needed to recognize and deal with complex problems—sensitive measurement techniques and sophisticated control technology—have been developed only within the past 20 years. For example, the automobile had been in use for more than 50 years before the technology was available to control exhaust gas emissions and before the science of atmospheric chemistry had matured to the point where the significance of this form of pollution could be fully appreciated. Less than 15 years ago, although scientists were aware that stratospheric gases played a role in limiting the amount of ultraviolet radiation that reaches Earth, it was not suspected that the integrity of the stratospheric gases was threatened by CFCs, substances that had been in common use in refrigerators since the 1940s. In Europe in the early 1960s, and in North America a decade later, scientists noticed that rain was becoming more acidic and predicted what would happen when this rain fell on trees, soils, and surface water. It took years, however, to pinpoint the exact causes of acidification and to convince a largely skeptical world of the seriousness of the problem. Since 1958, researchers have monitored the carbon dioxide content of the atmosphere in remote parts of the world (Bacastow and Keeling 1981). They determined that carbon dioxide levels were rising steadily and predicted global warming as a consequence, which made this an issue of importance to all nations.

All of these studies began with basic scientific curiosity, but the findings have given legitimacy to these pioneers' predictions of serious environmental change. These predictions are now generally supported by the scientific community. The need to search for solutions to these problems has gained political momentum. Environmental issues rank high on political agendas, and progress is being made toward resolving these air pollution issues.

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